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(12) **United States Patent**  
**Rogers**

(10) **Patent No.:** **US 10,938,082 B2**  
(45) **Date of Patent:** **Mar. 2, 2021**

(54) **APERTURE-COUPLED  
MICROSTRIP-TO-WAVEGUIDE  
TRANSITIONS**

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(US)

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(73) Assignee: **THE BOEING COMPANY**, Chicago,  
IL (US)

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 96 days.

(Continued)

(21) Appl. No.: **16/111,830**

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(22) Filed: **Aug. 24, 2018**

(74) *Attorney, Agent, or Firm* — Moore IP Law

(65) **Prior Publication Data**

(57) **ABSTRACT**

US 2020/0067165 A1 Feb. 27, 2020

(51) **Int. Cl.**  
**H01Q 9/04** (2006.01)  
**H01Q 9/06** (2006.01)  
(Continued)

An aperture coupled microstrip-to-waveguide transition ("ACMWT") is disclosed that includes a plurality of dielectric layers forming a dielectric structure and an inner conductor formed within the dielectric structure. The plurality of dielectric layers includes a top dielectric layer that has a top surface. The ("ACMWT") further includes a patch antenna element ("PAE") formed on the top surface, a bottom conductor, an antenna slot within the PAE, a coupling element ("CE") formed above the inner conductor and below the PAE, and a waveguide. The waveguide includes at least one waveguide wall and a waveguide backend, where the waveguide backend has a waveguide backend surface that's a portion of the top surface of the top dielectric layer and where the waveguide backend surface and the at least one waveguide wall form a waveguide cavity within the waveguide. The PAE is a conductor located within the waveguide cavity at the waveguide backend surface.

(52) **U.S. Cl.**  
CPC ..... **H01P 5/085** (2013.01); **H01P 3/08** (2013.01); **H01P 3/12** (2013.01); **H01P 11/002** (2013.01);  
(Continued)

(58) **Field of Classification Search**  
CPC .... H01Q 9/045; H01Q 21/065; H01Q 9/0414; H01Q 21/0075; H01Q 13/06;  
(Continued)

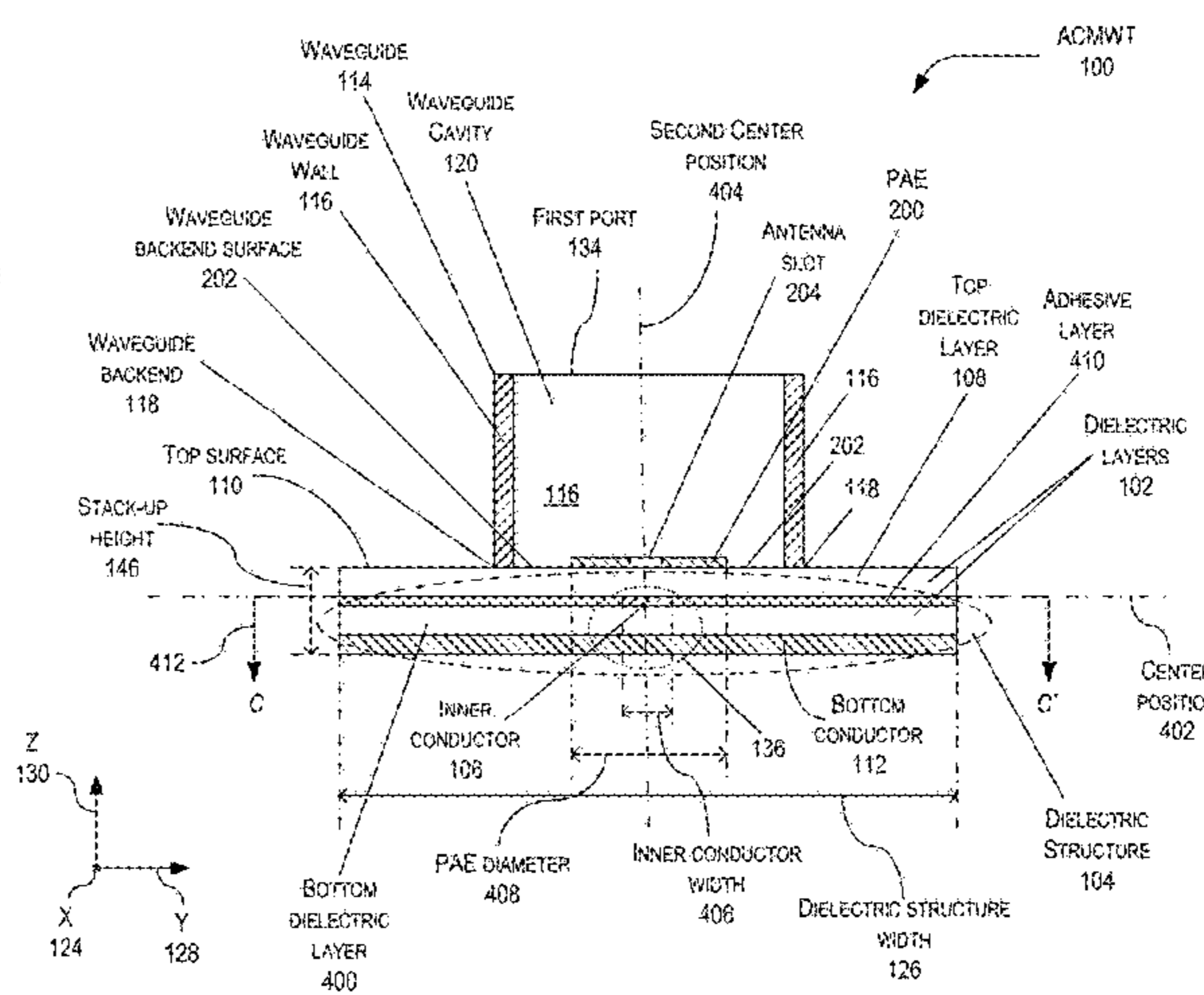
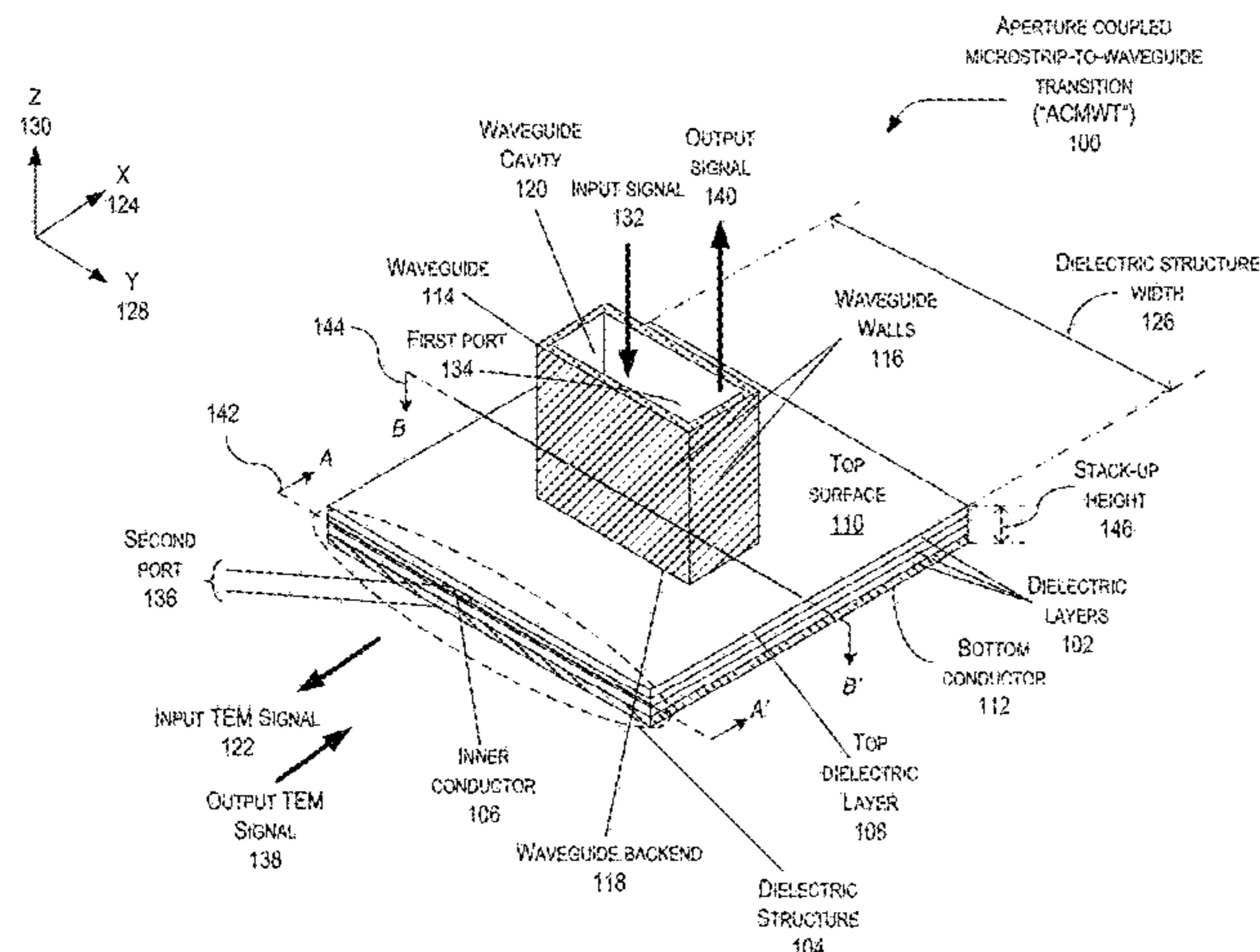
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**20 Claims, 26 Drawing Sheets**



- (51) **Int. Cl.**  
*H01P 5/08* (2006.01)  
*H01P 3/08* (2006.01)  
*H01P 11/00* (2006.01)  
*H01P 3/12* (2006.01)  
*H01Q 21/06* (2006.01)
- (52) **U.S. Cl.**  
 CPC ..... *H01P 11/003* (2013.01); *H01Q 9/045* (2013.01); *H01Q 21/065* (2013.01)
- (58) **Field of Classification Search**  
 CPC ..... H01P 5/085; H01P 3/12; H01P 11/003; H01P 11/002; H01P 3/08; H01P 5/107  
 See application file for complete search history.

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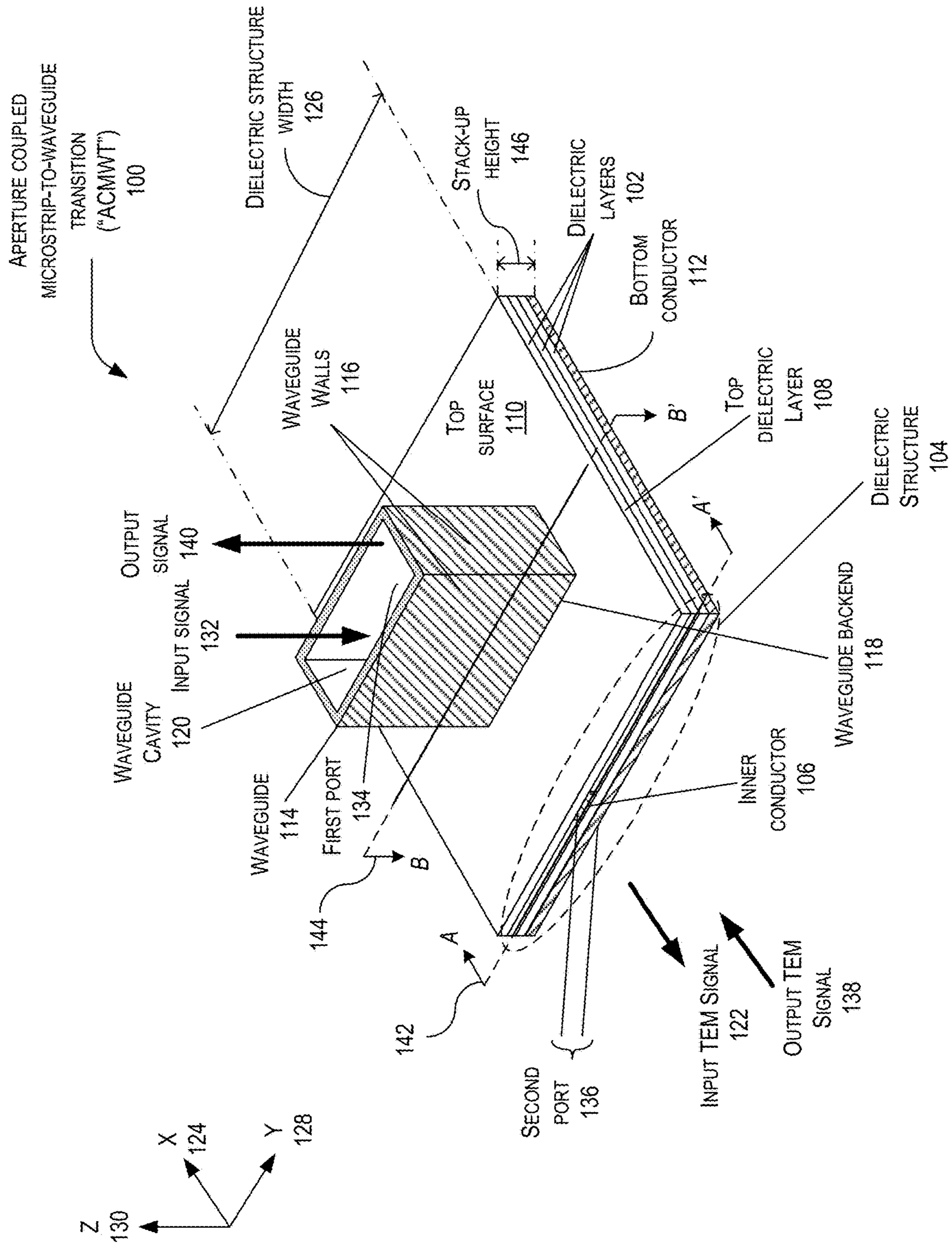


FIG. 1

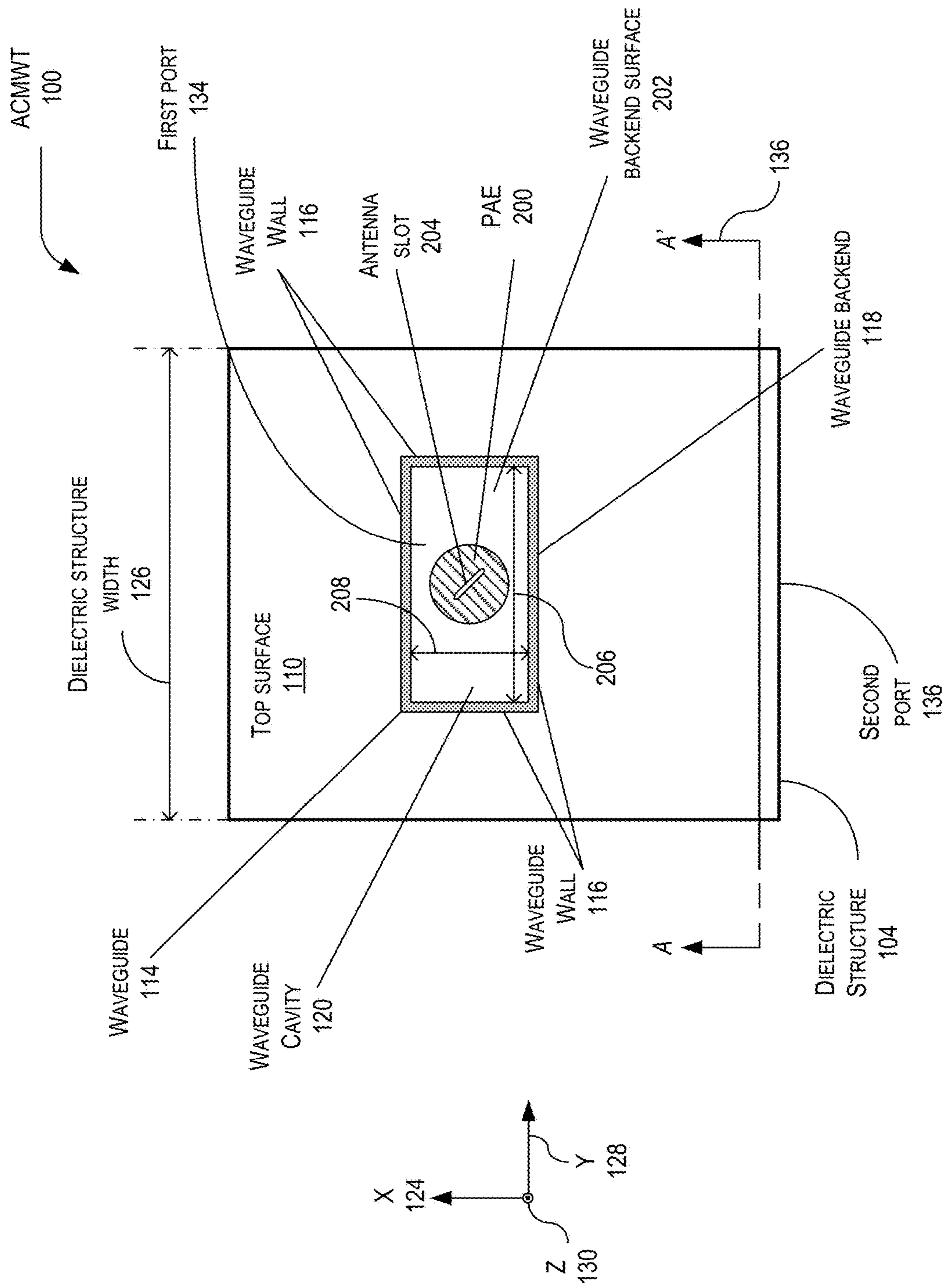


FIG. 2

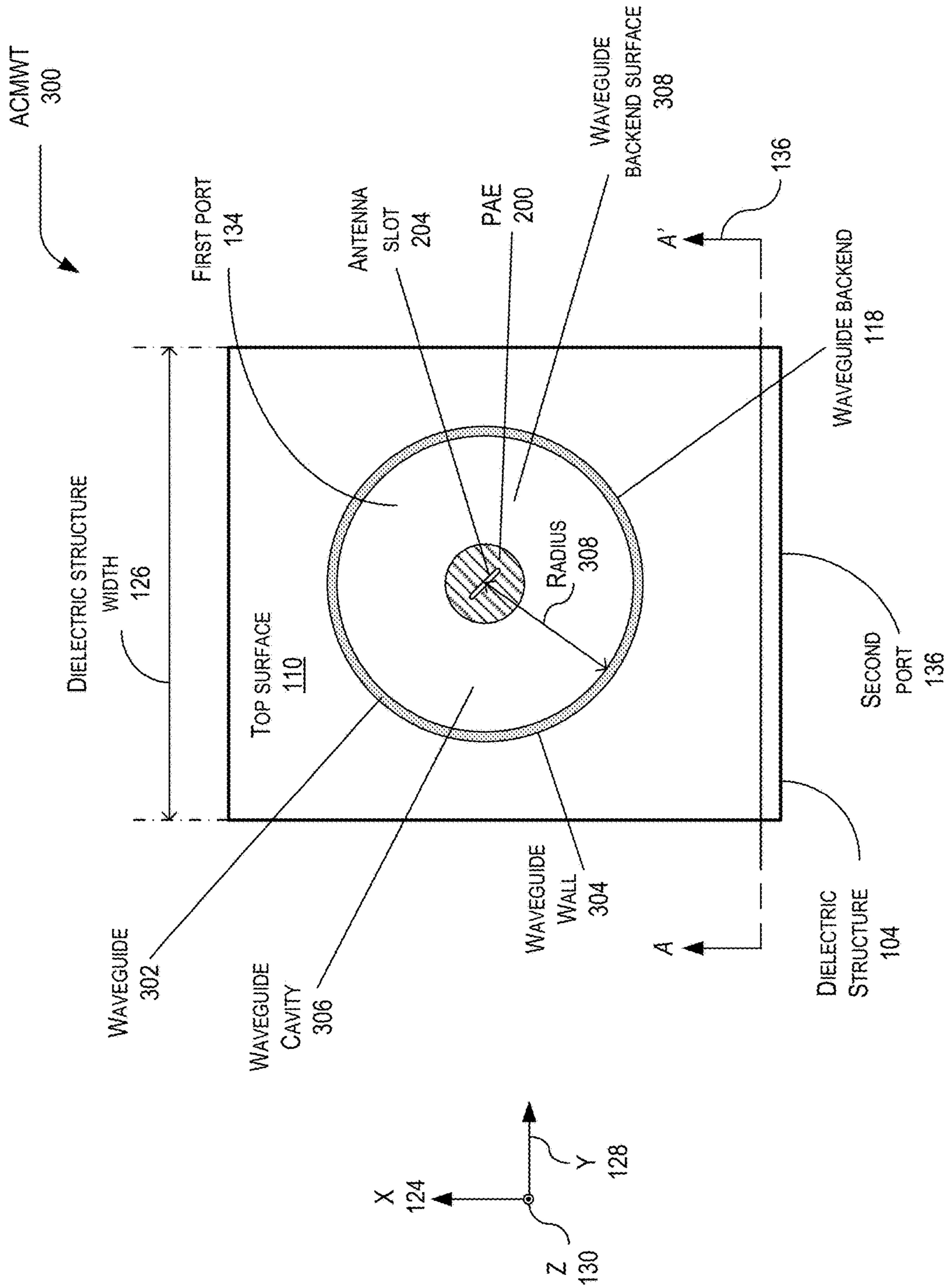


FIG. 3

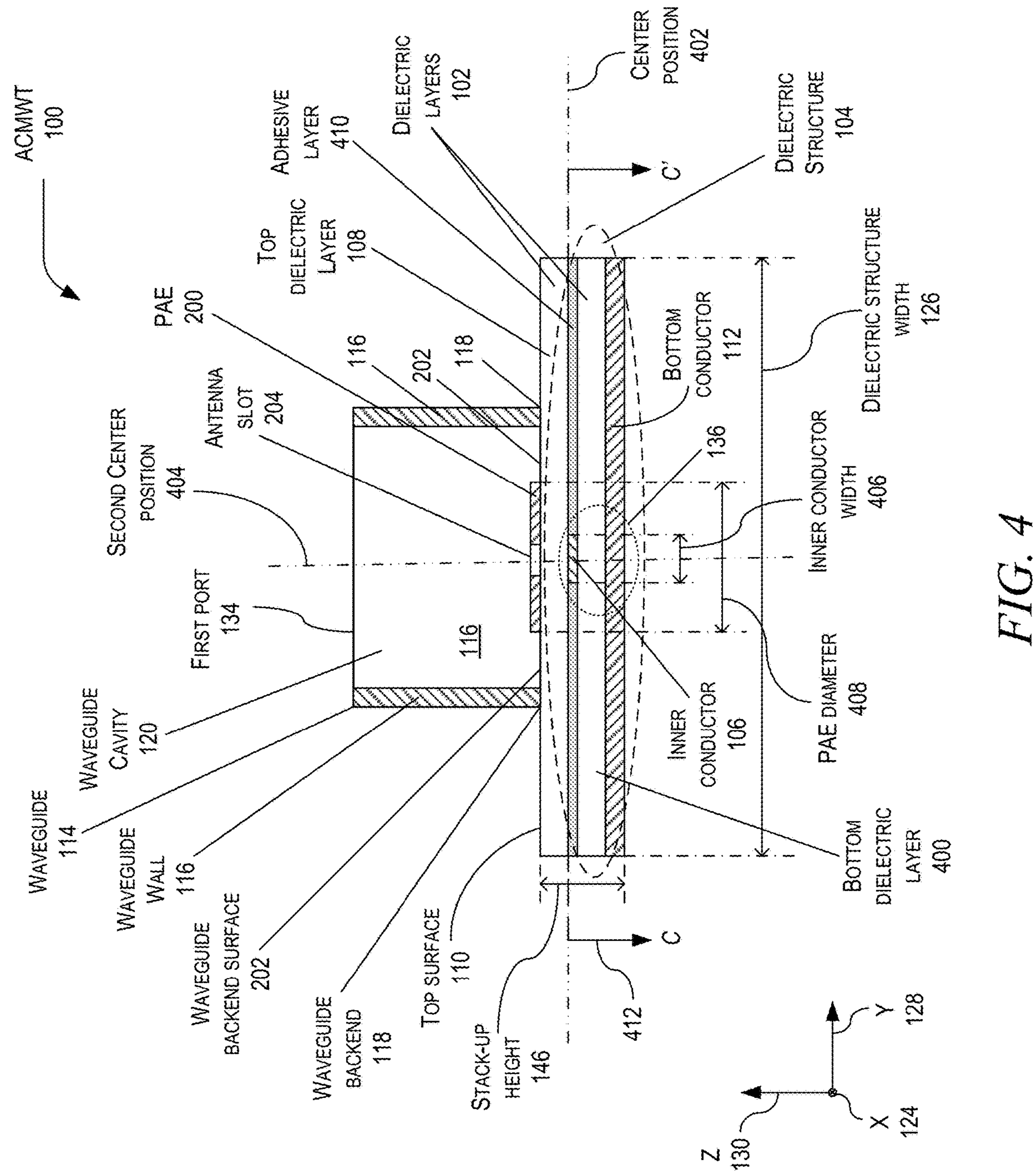


FIG. 4

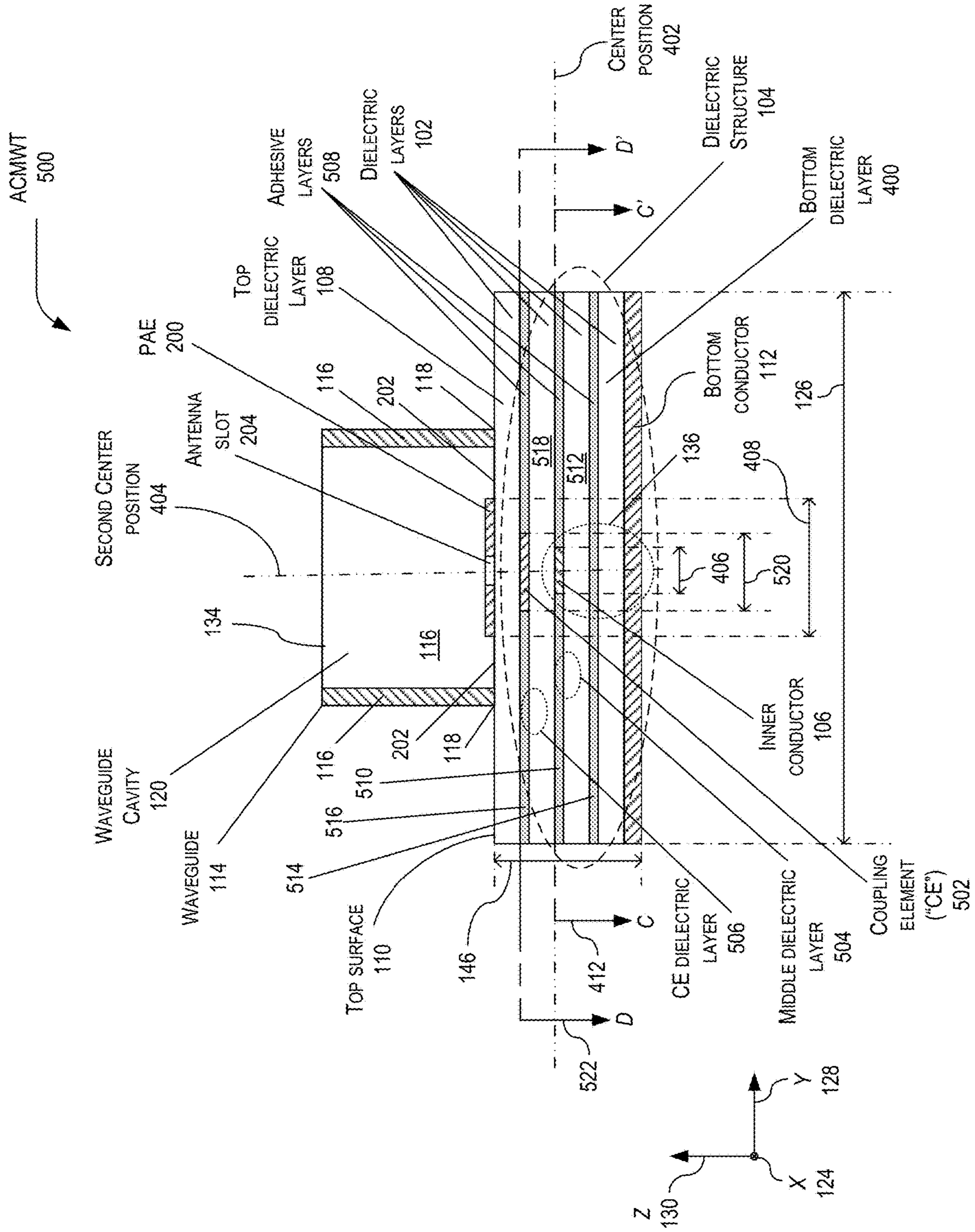


FIG. 5



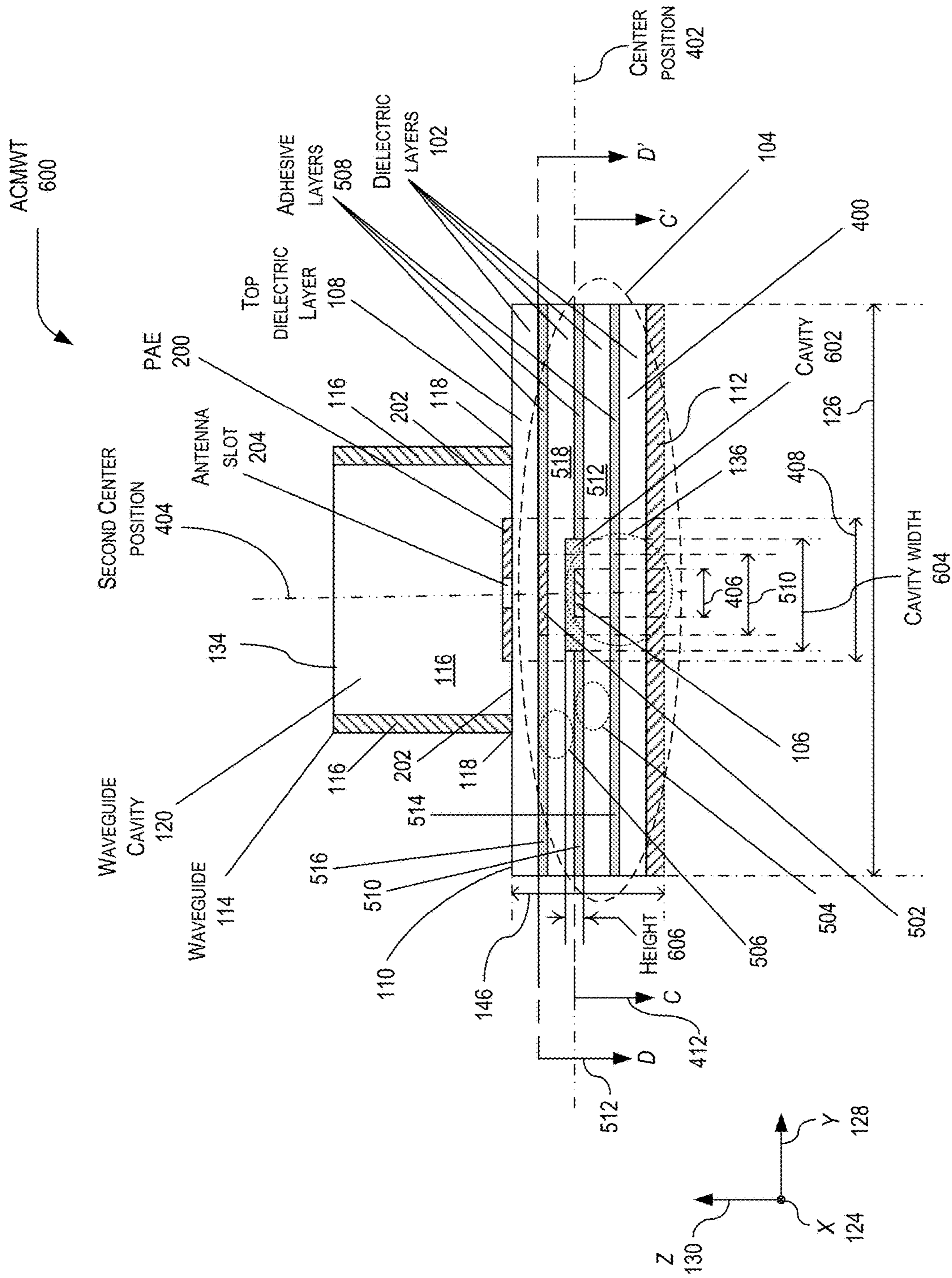


FIG. 6

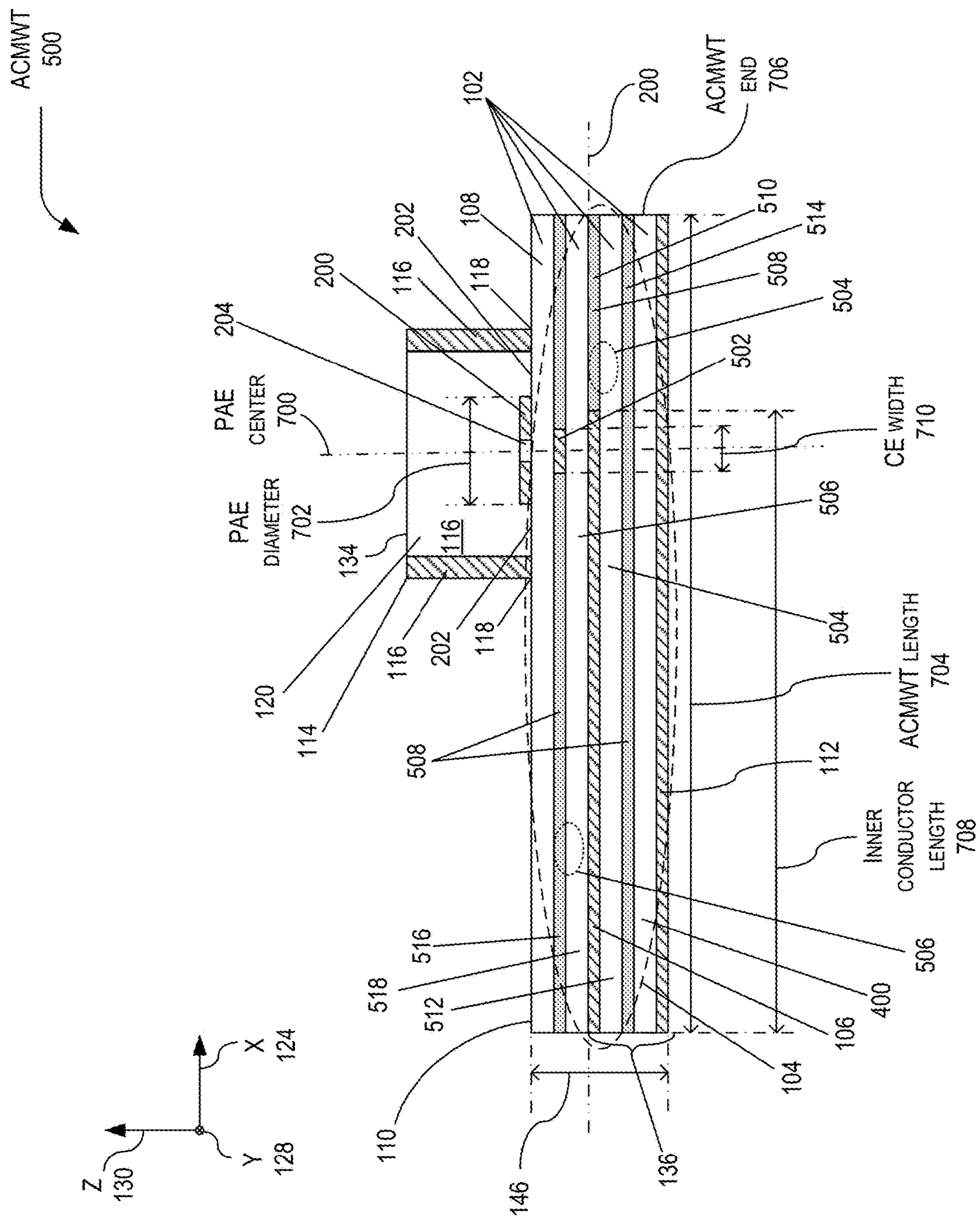


FIG. 7

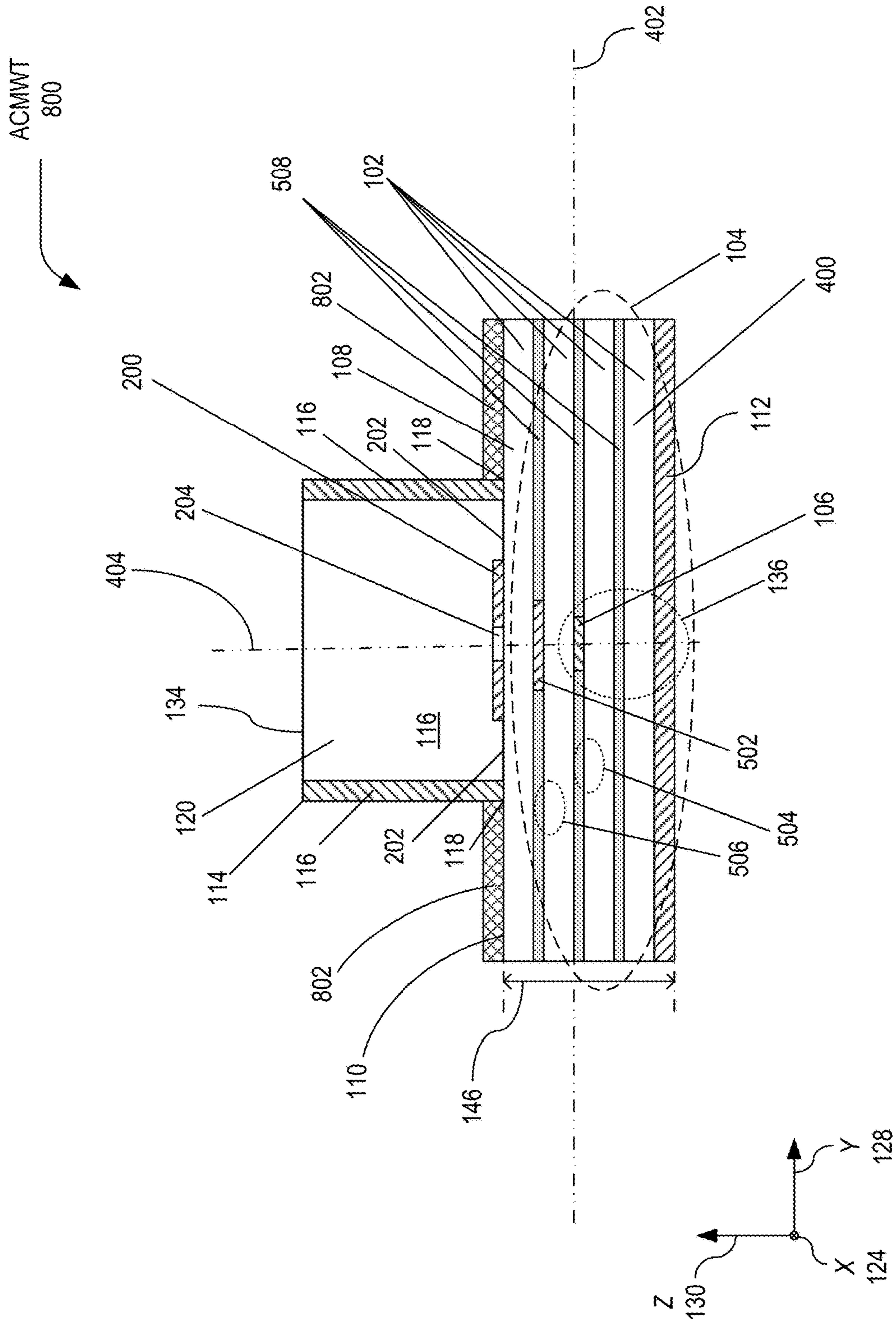


FIG. 8A

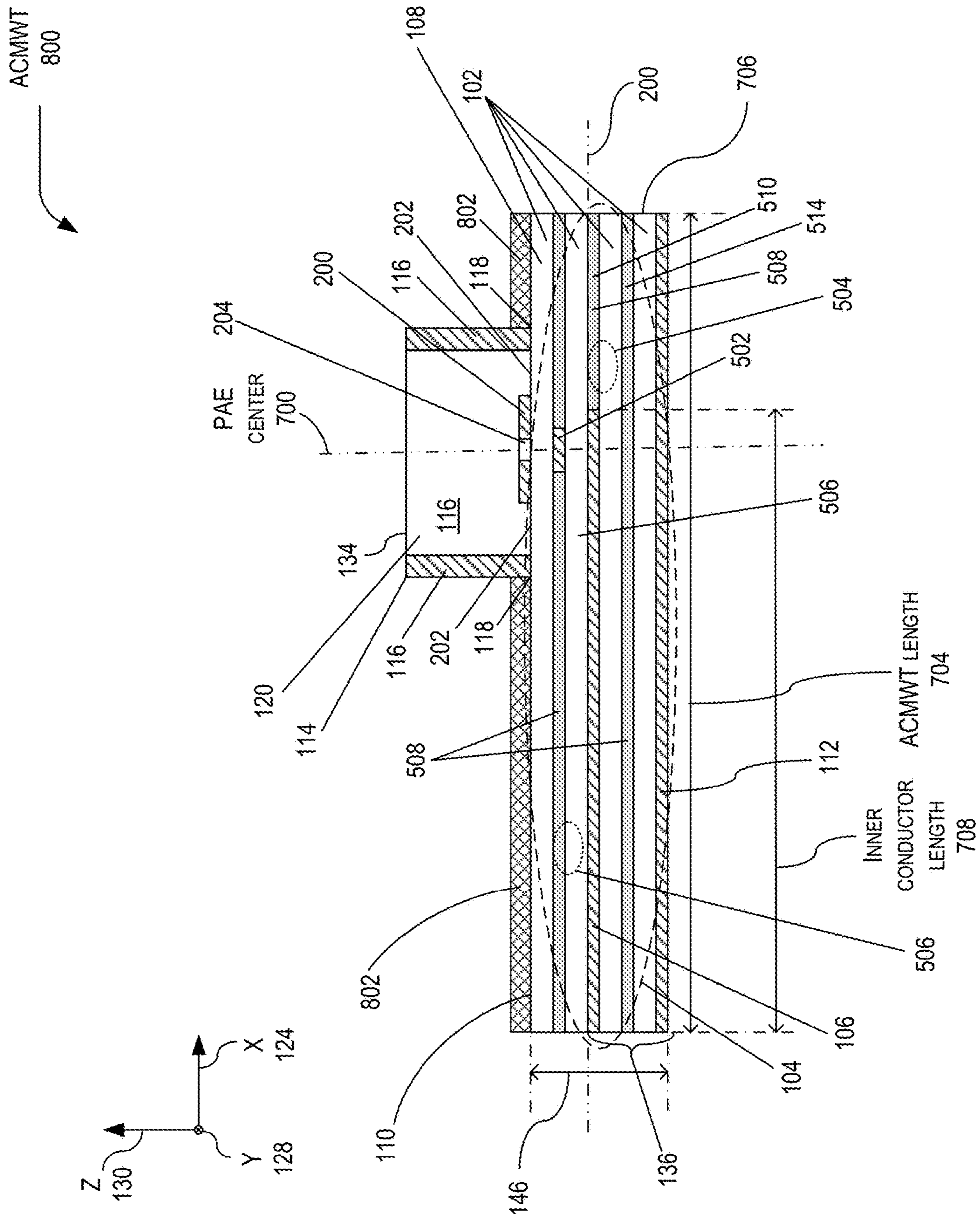


FIG. 8B

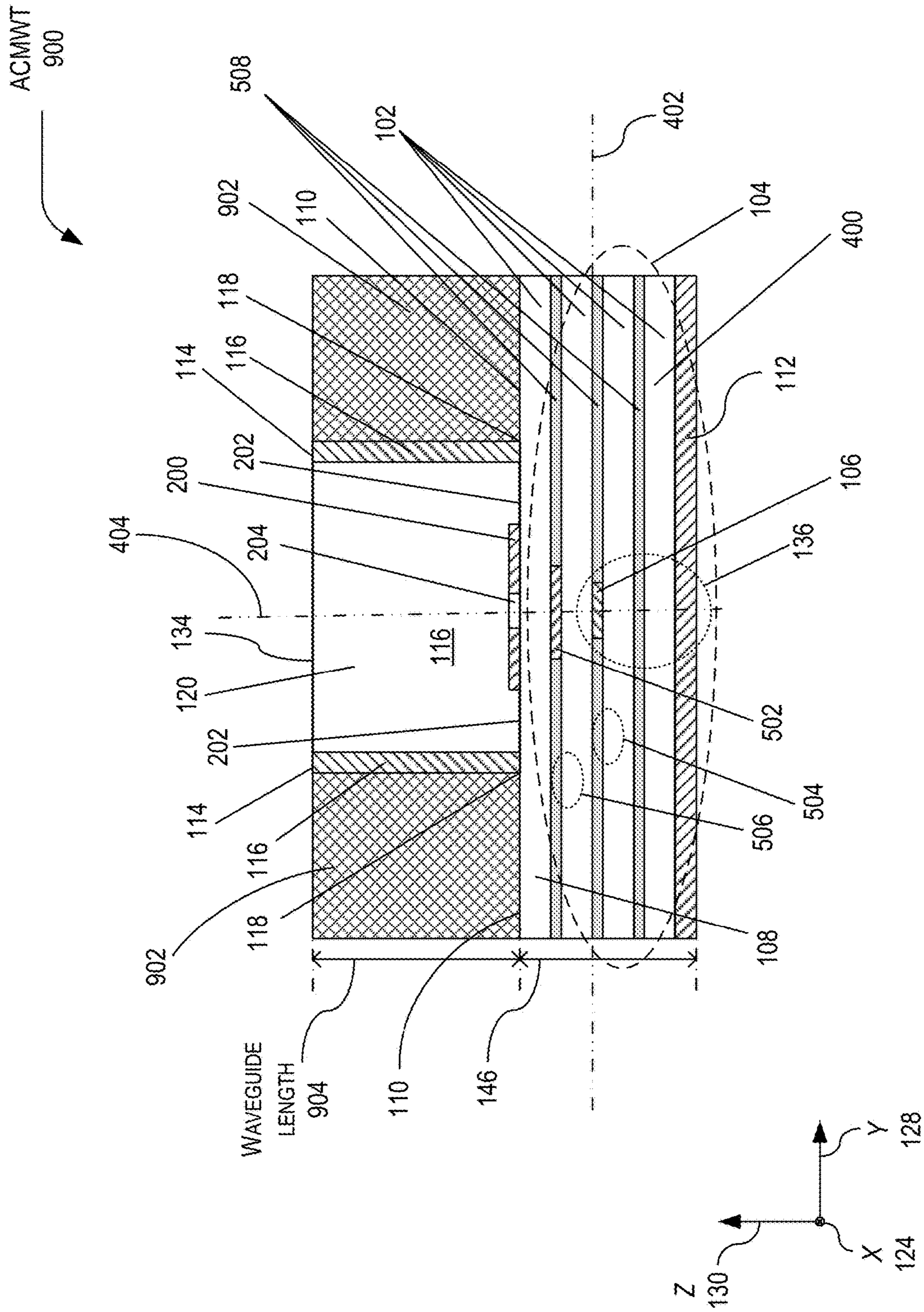


FIG. 9A



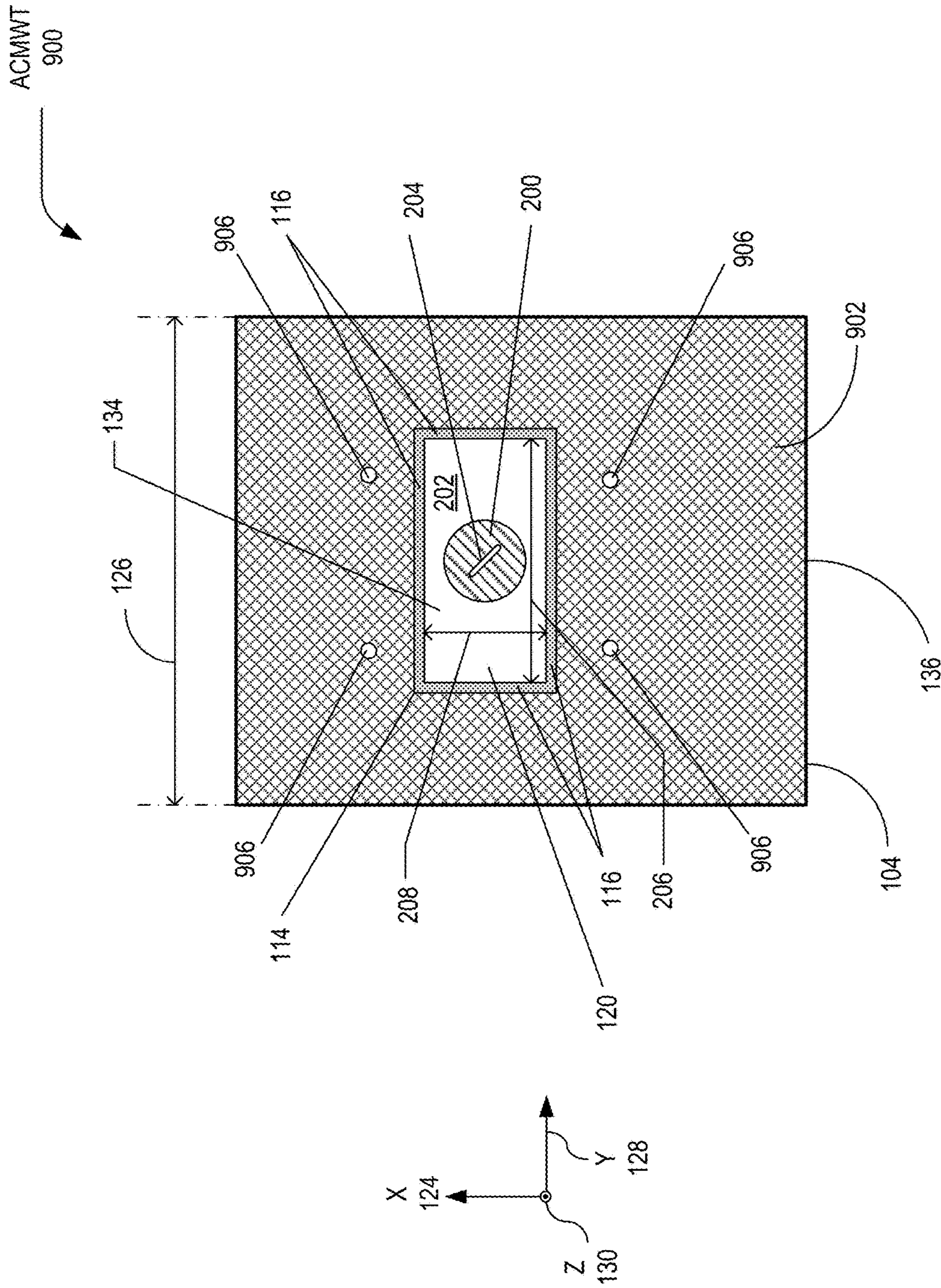


FIG. 9C

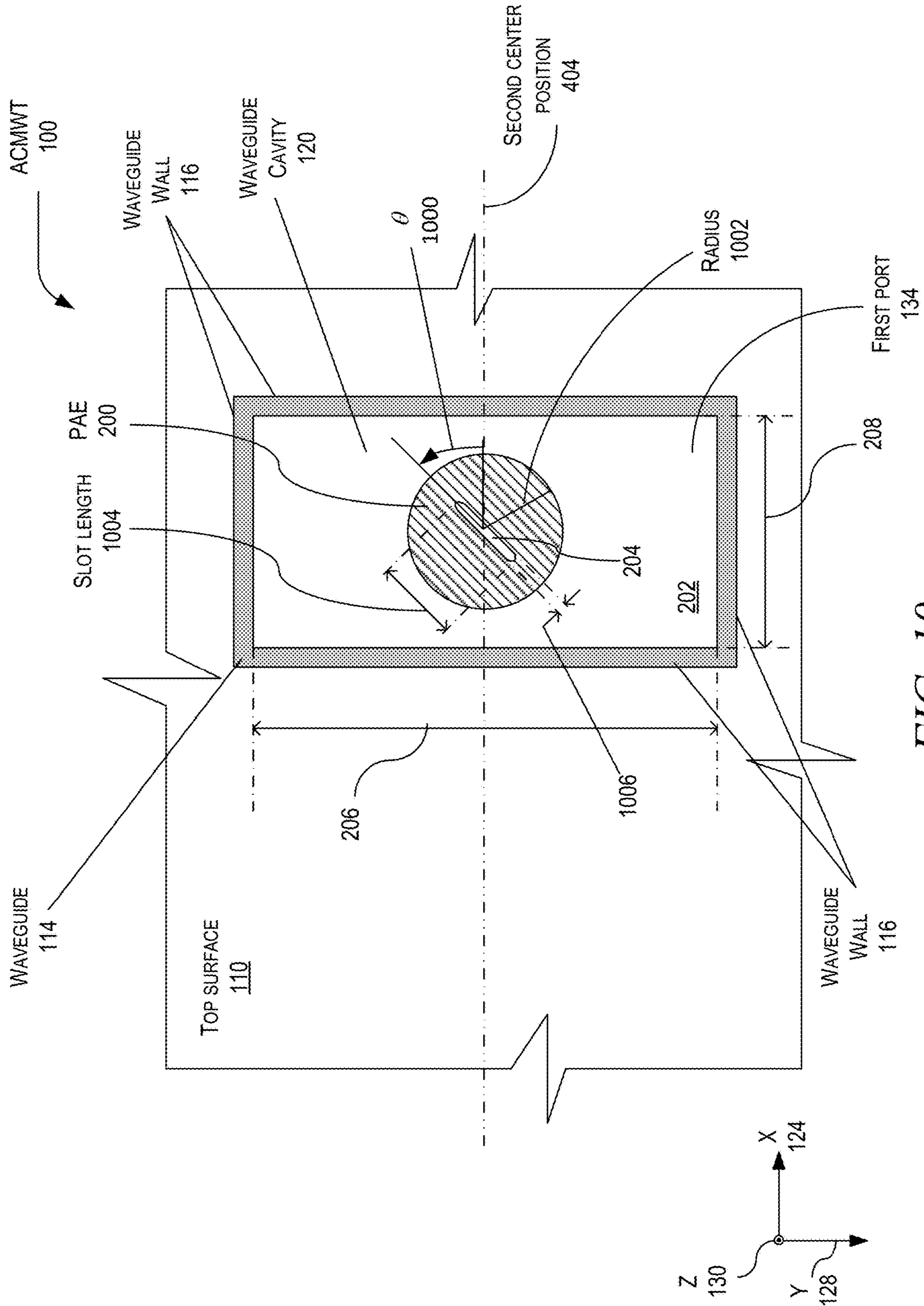


FIG. 10



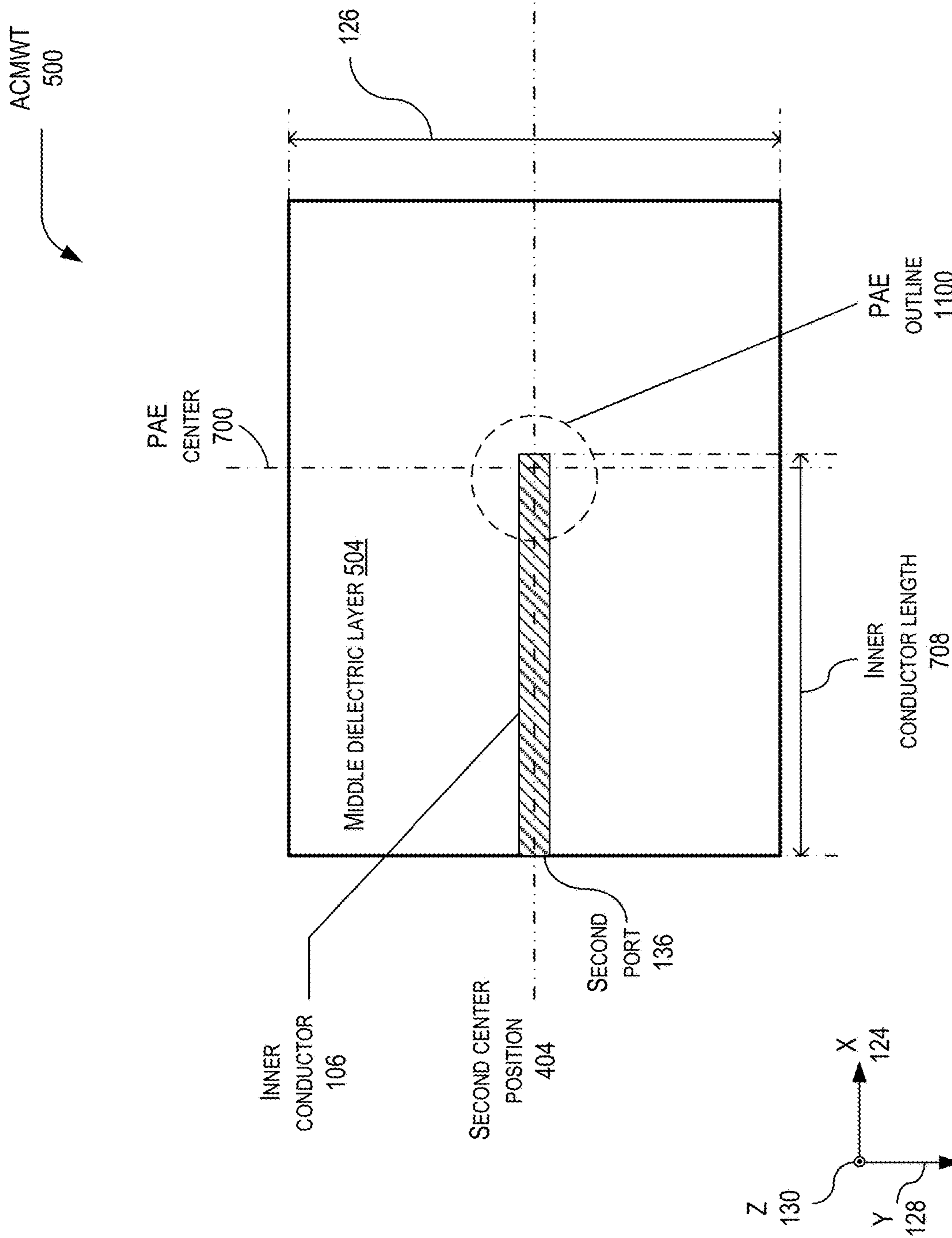


FIG. 11

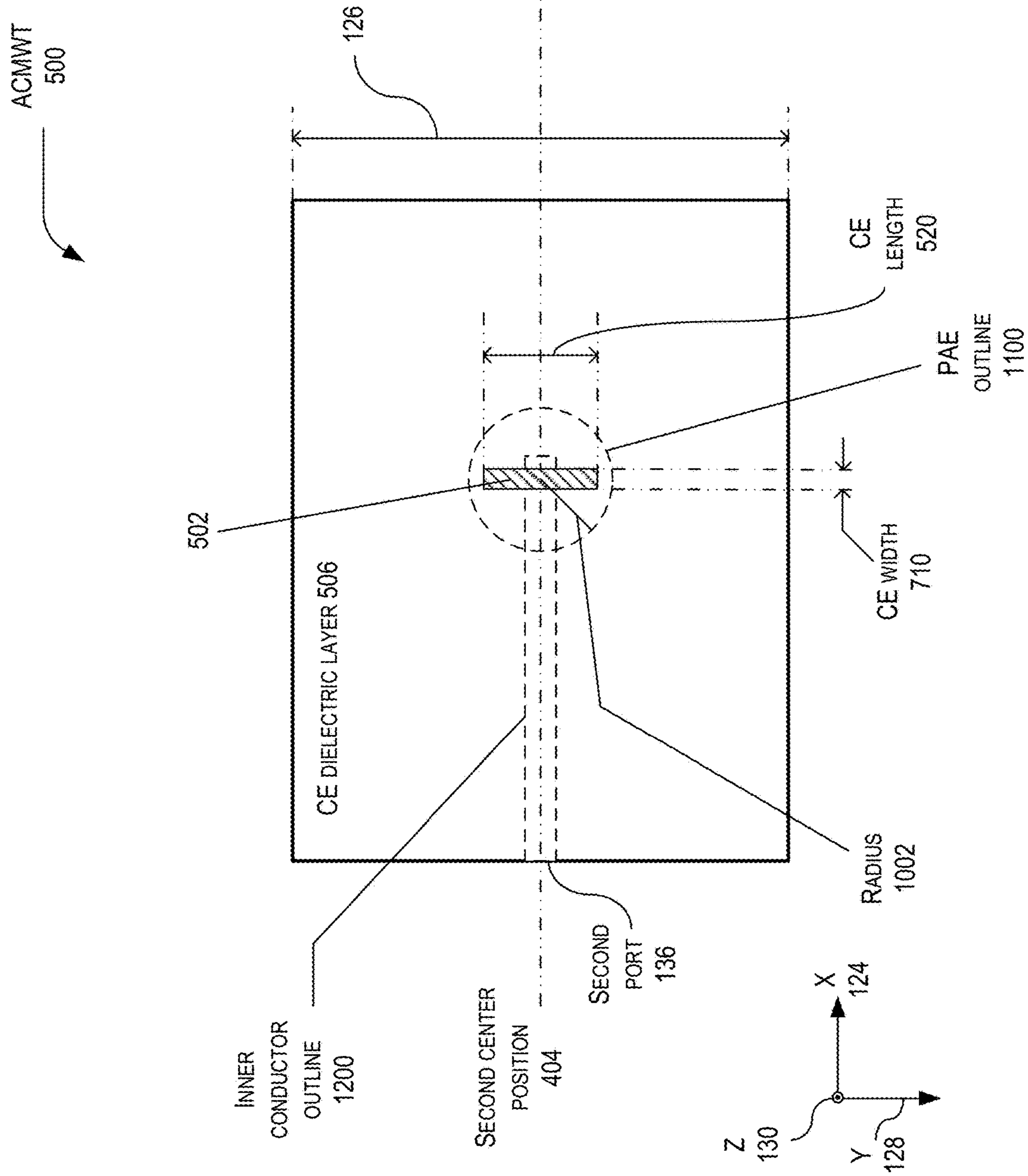


FIG. 12

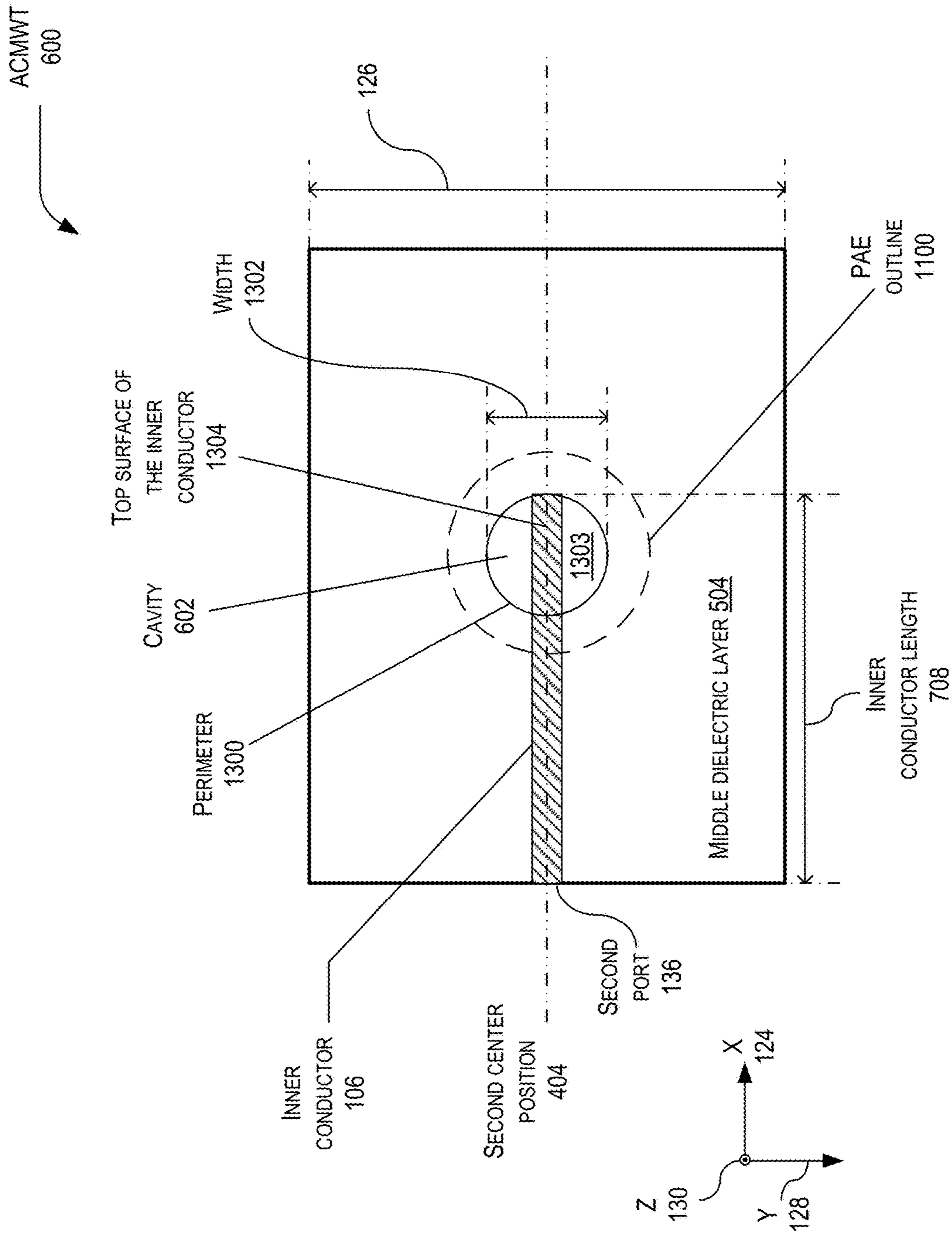


FIG. 13

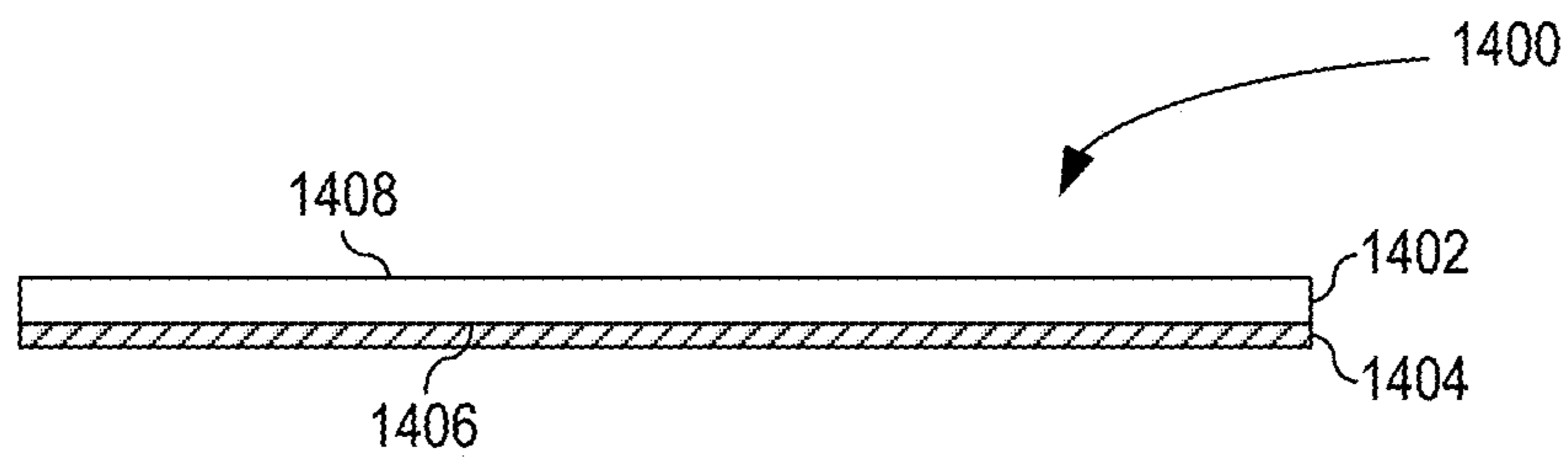


FIG. 14A

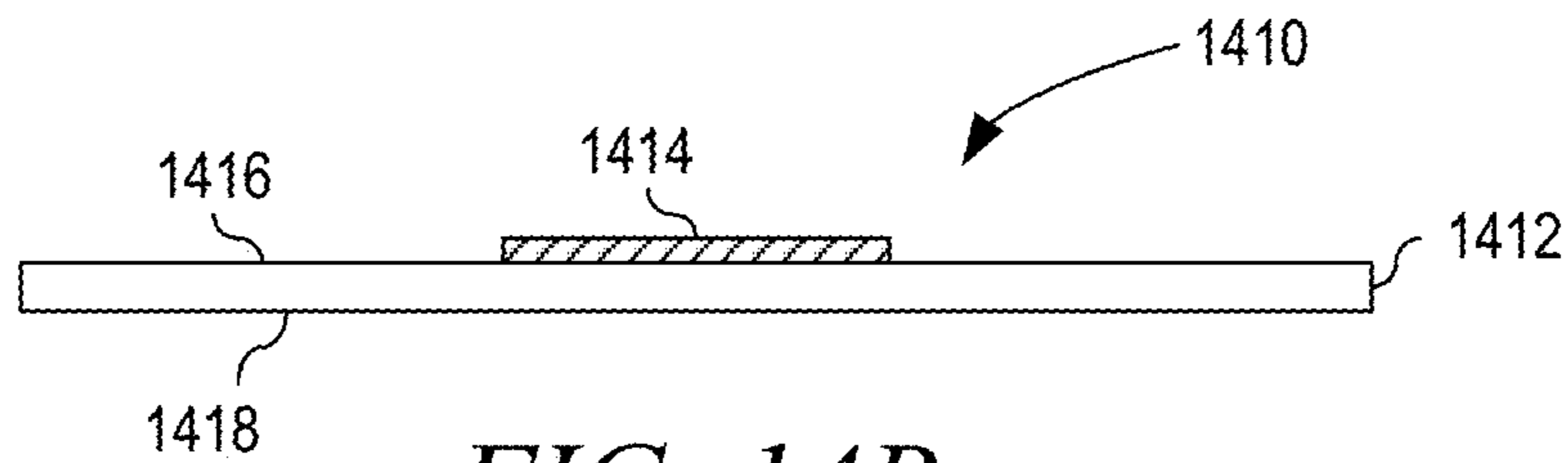


FIG. 14B

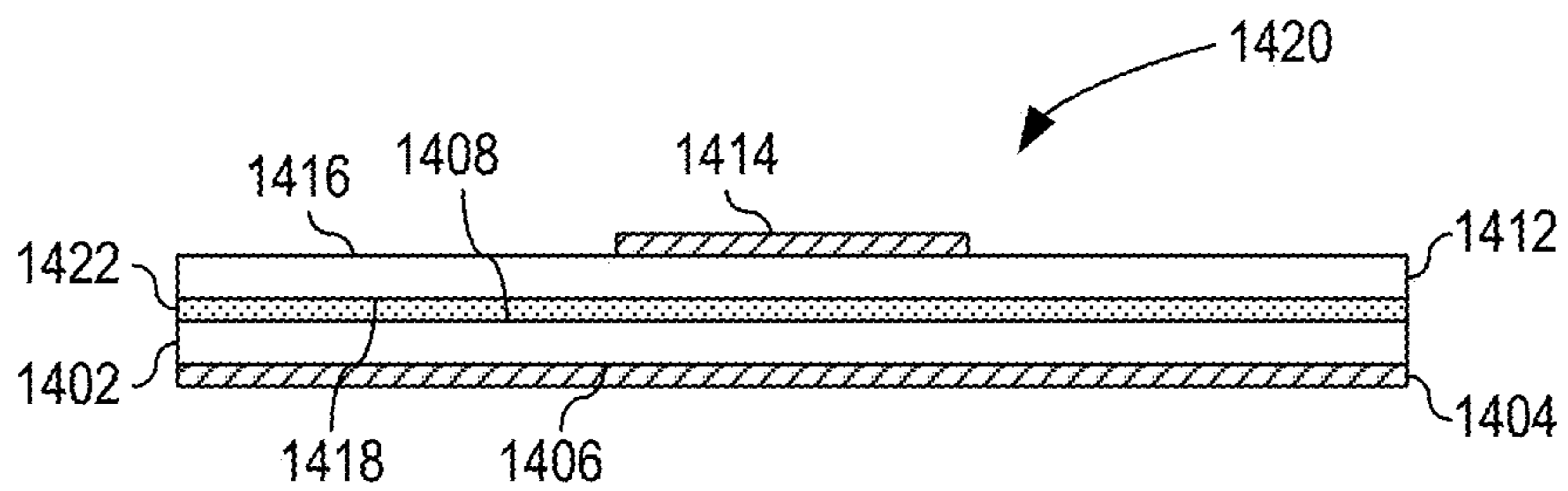


FIG. 14C

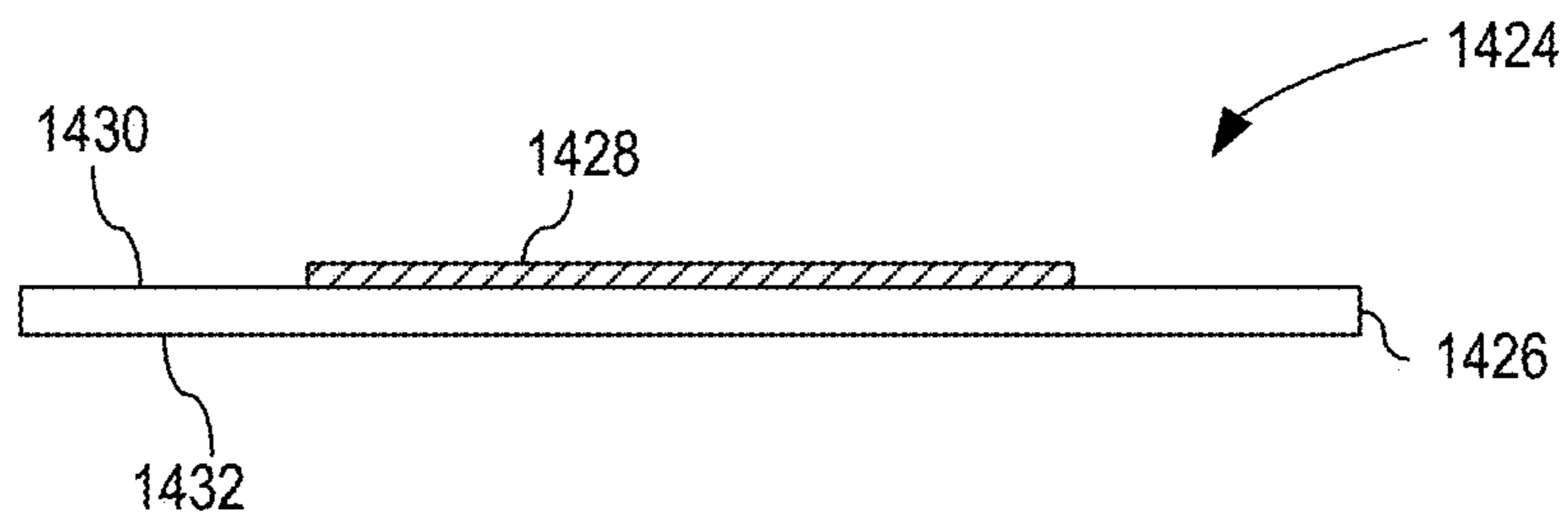


FIG. 14D

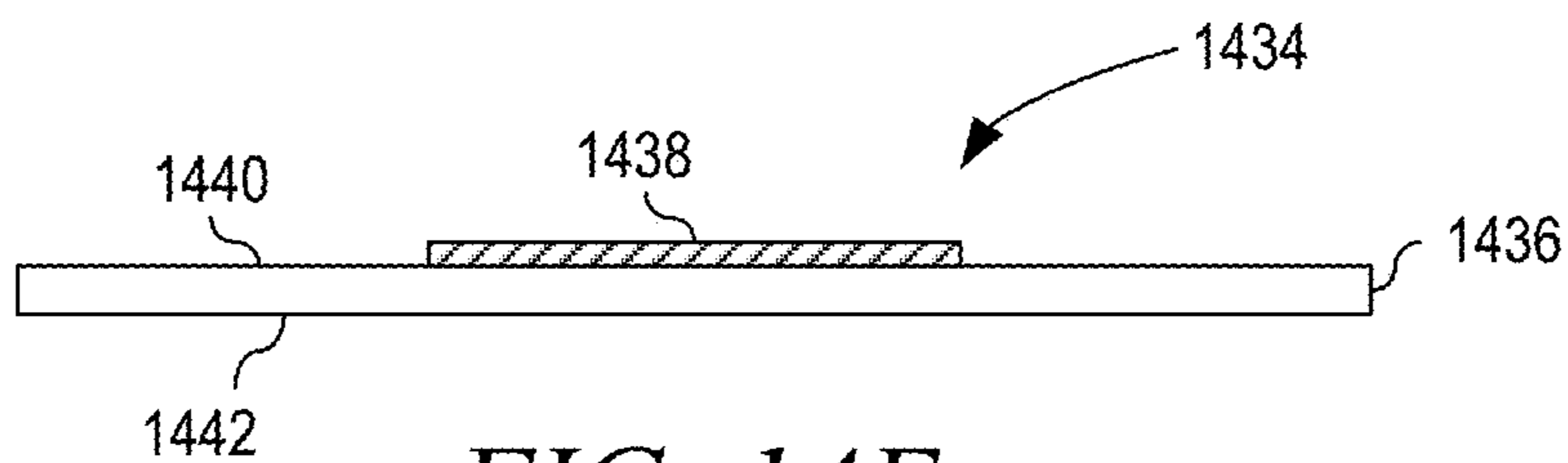


FIG. 14E

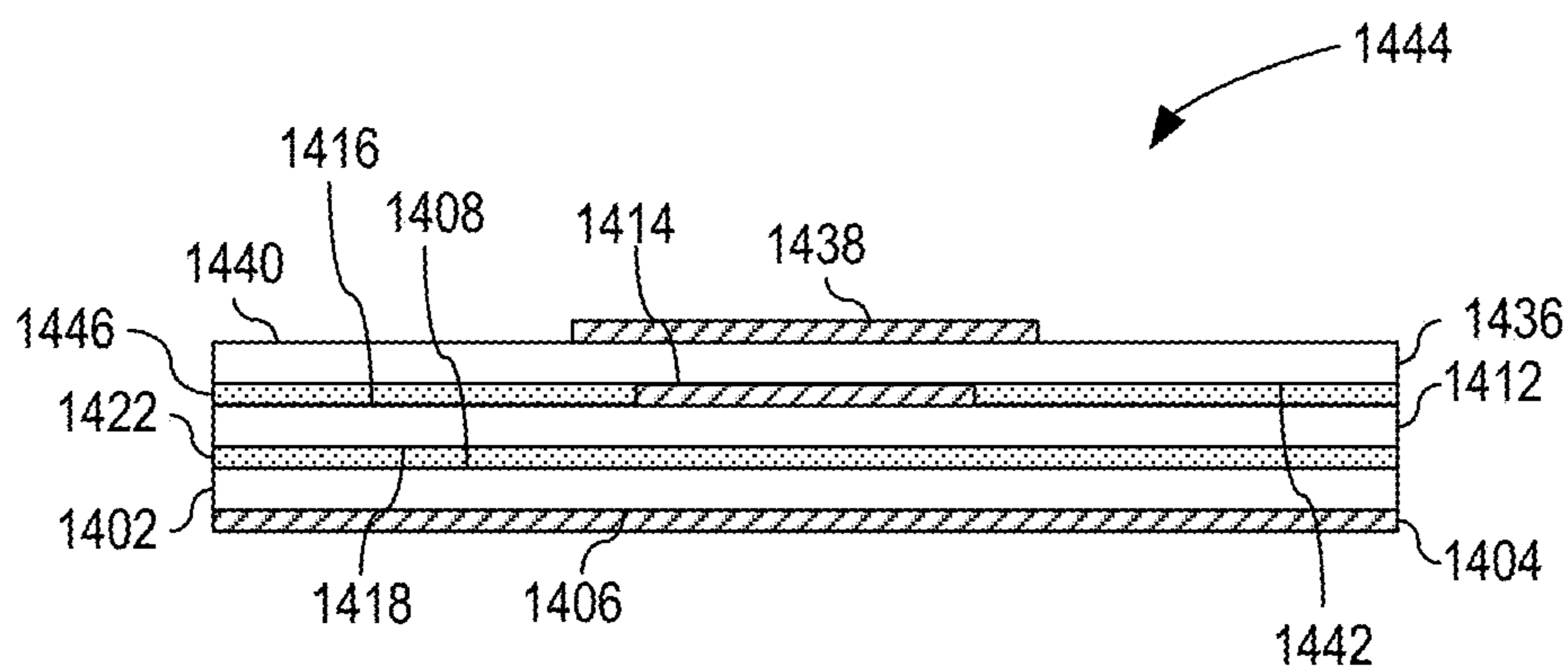


FIG. 14F

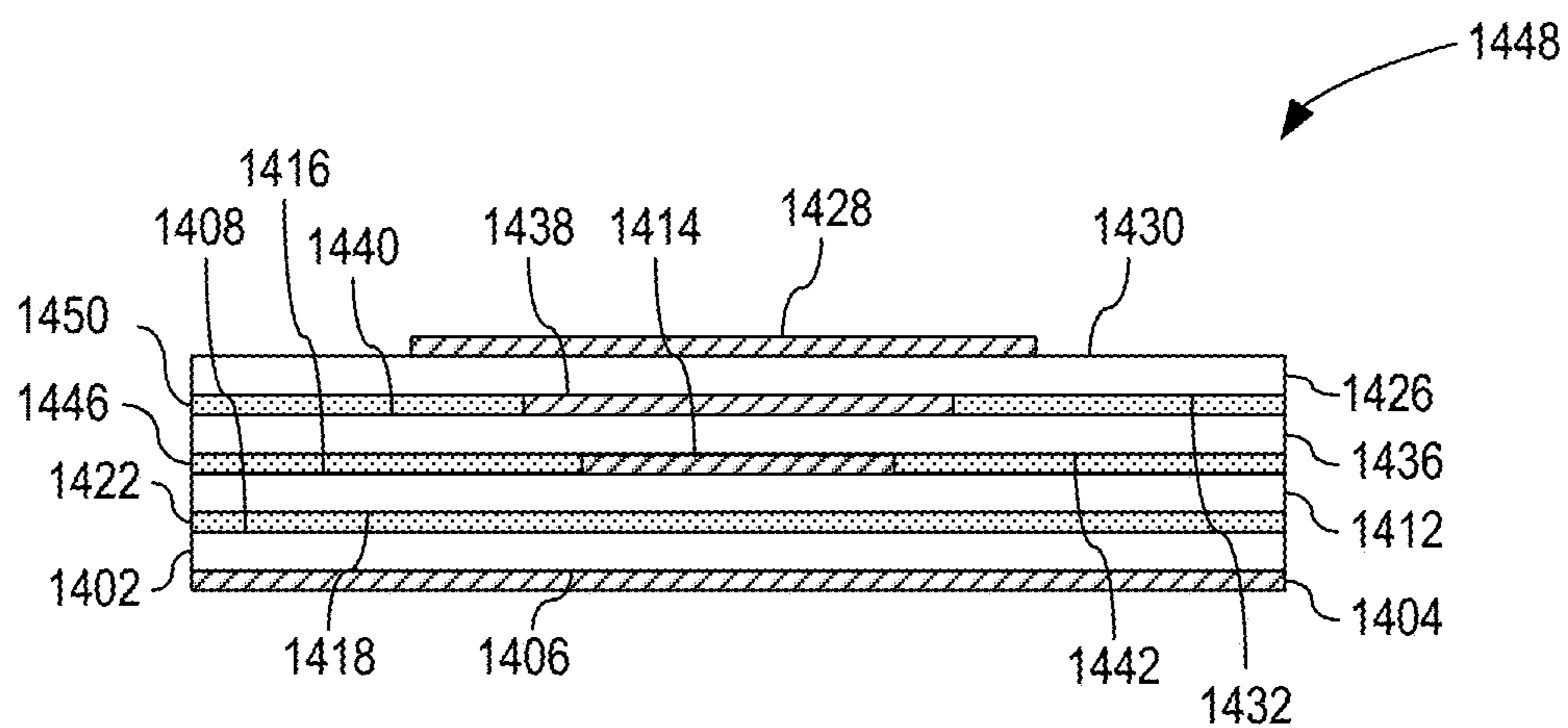


FIG. 14G

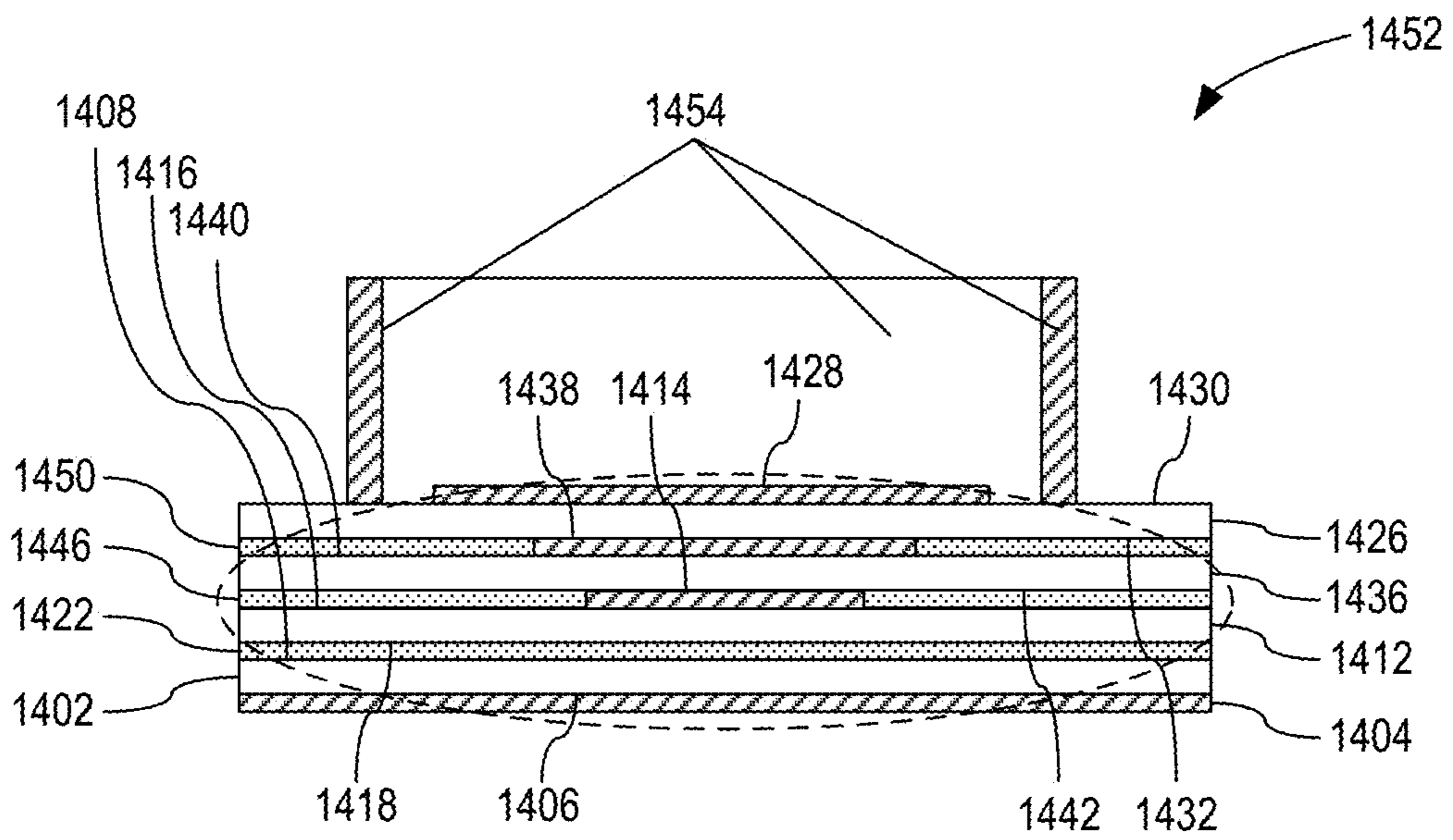


FIG. 14H

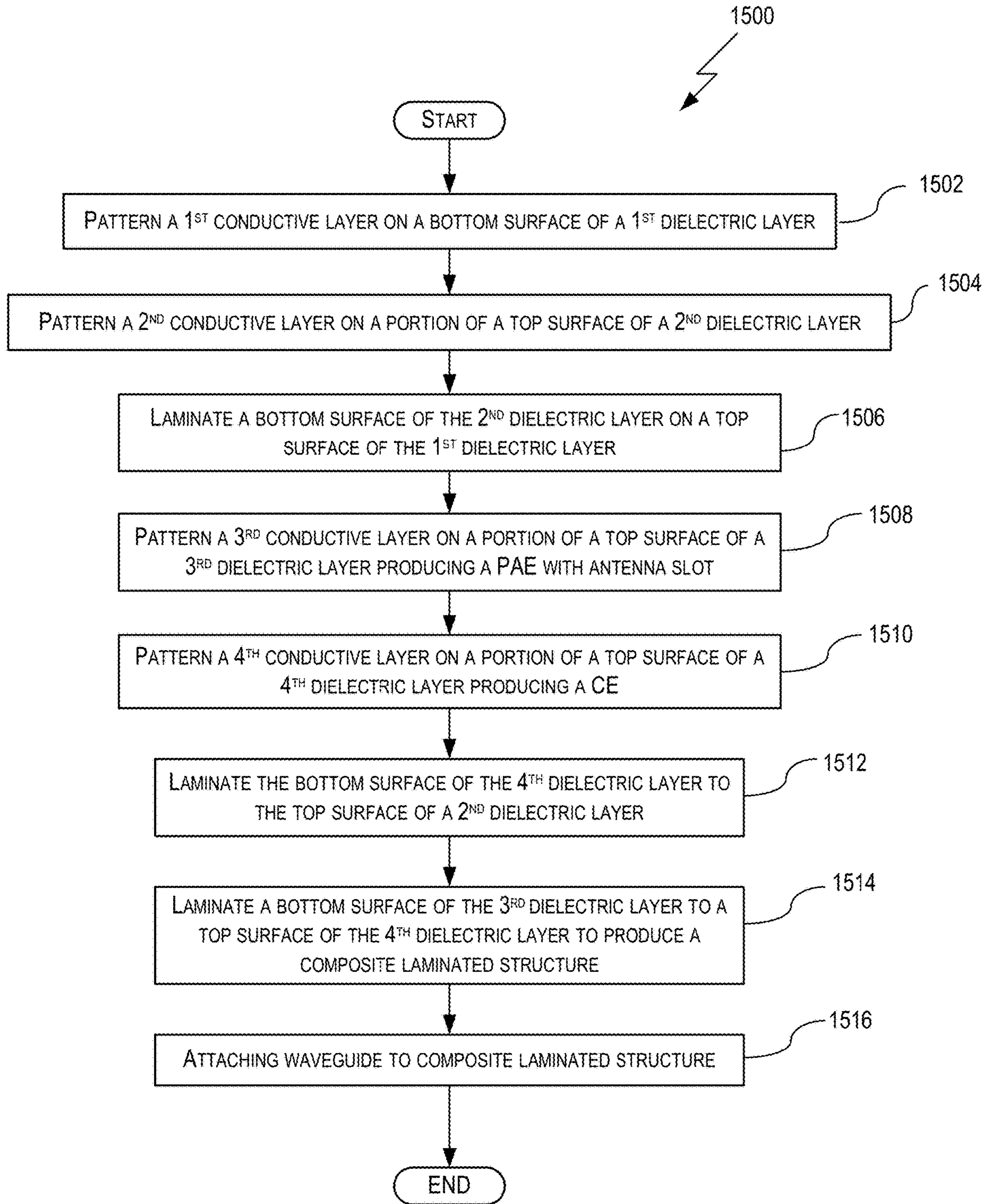


FIG. 15

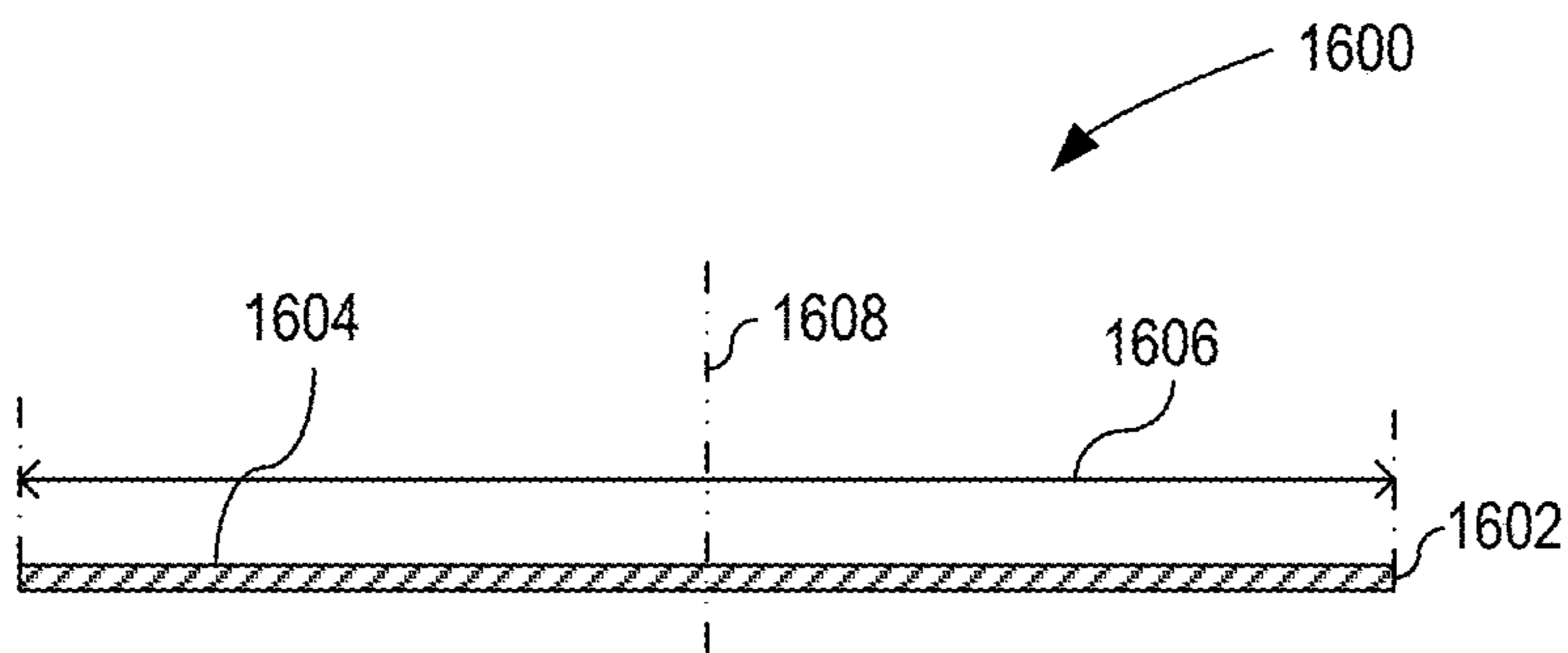


FIG. 16A

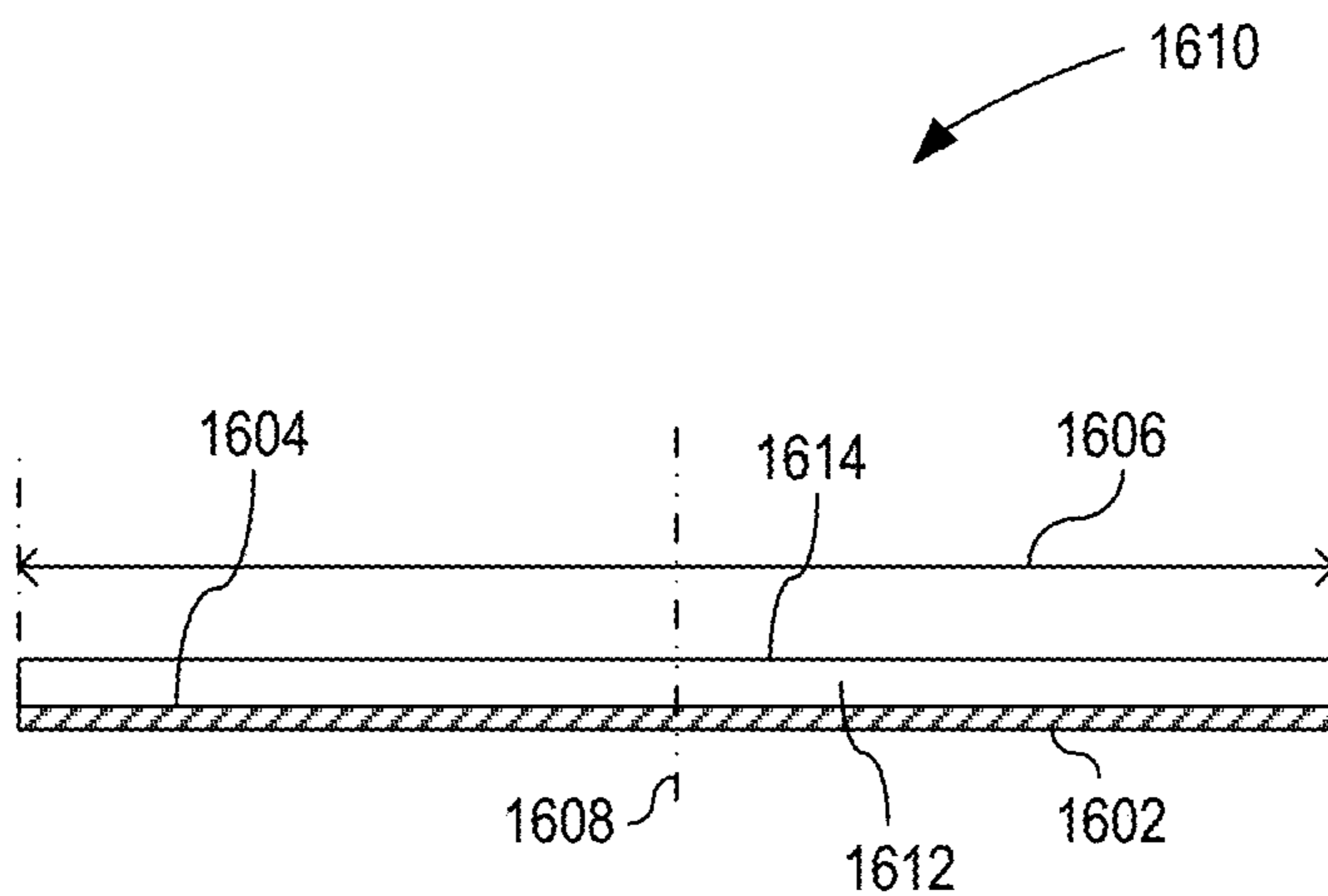


FIG. 16B

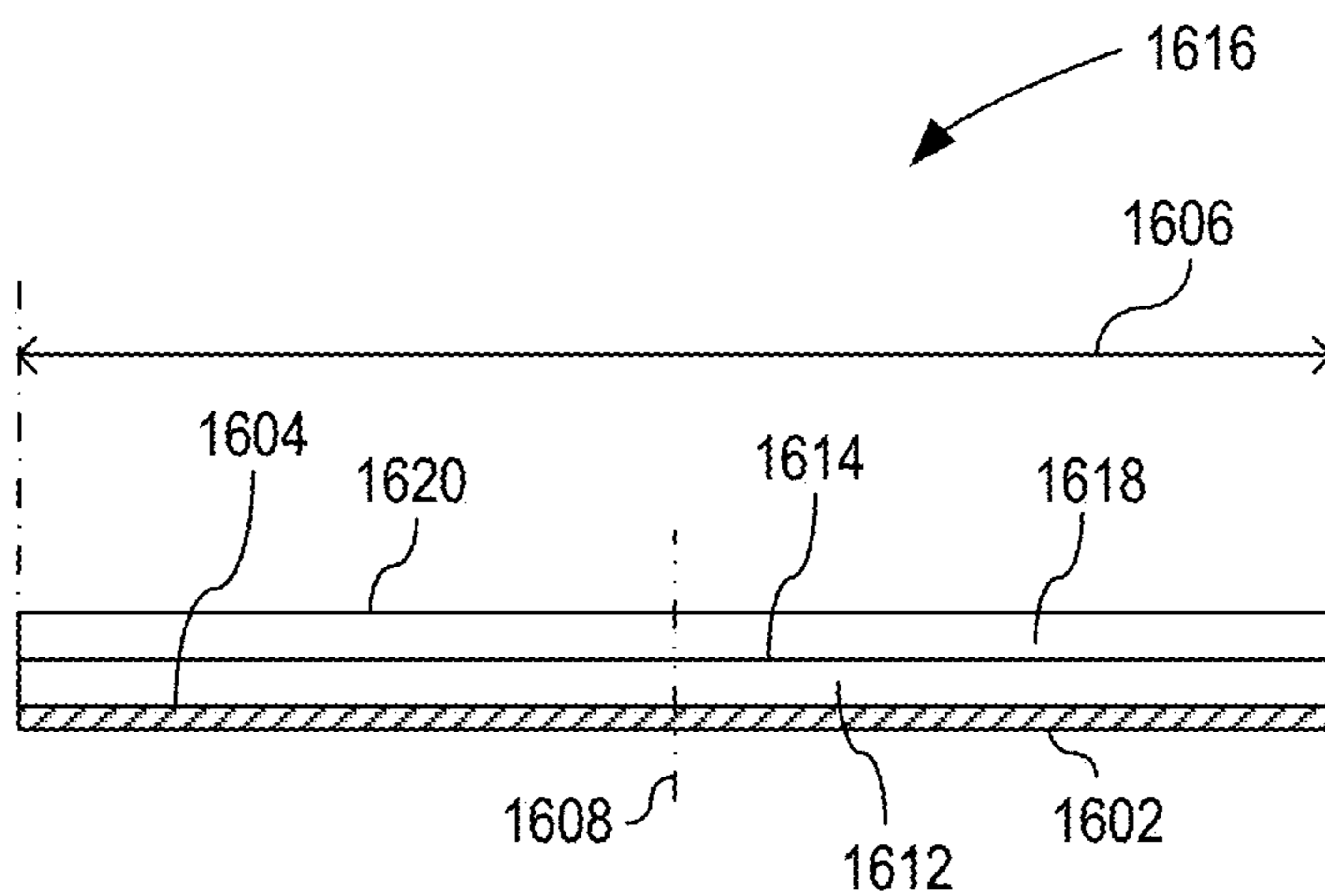


FIG. 16C





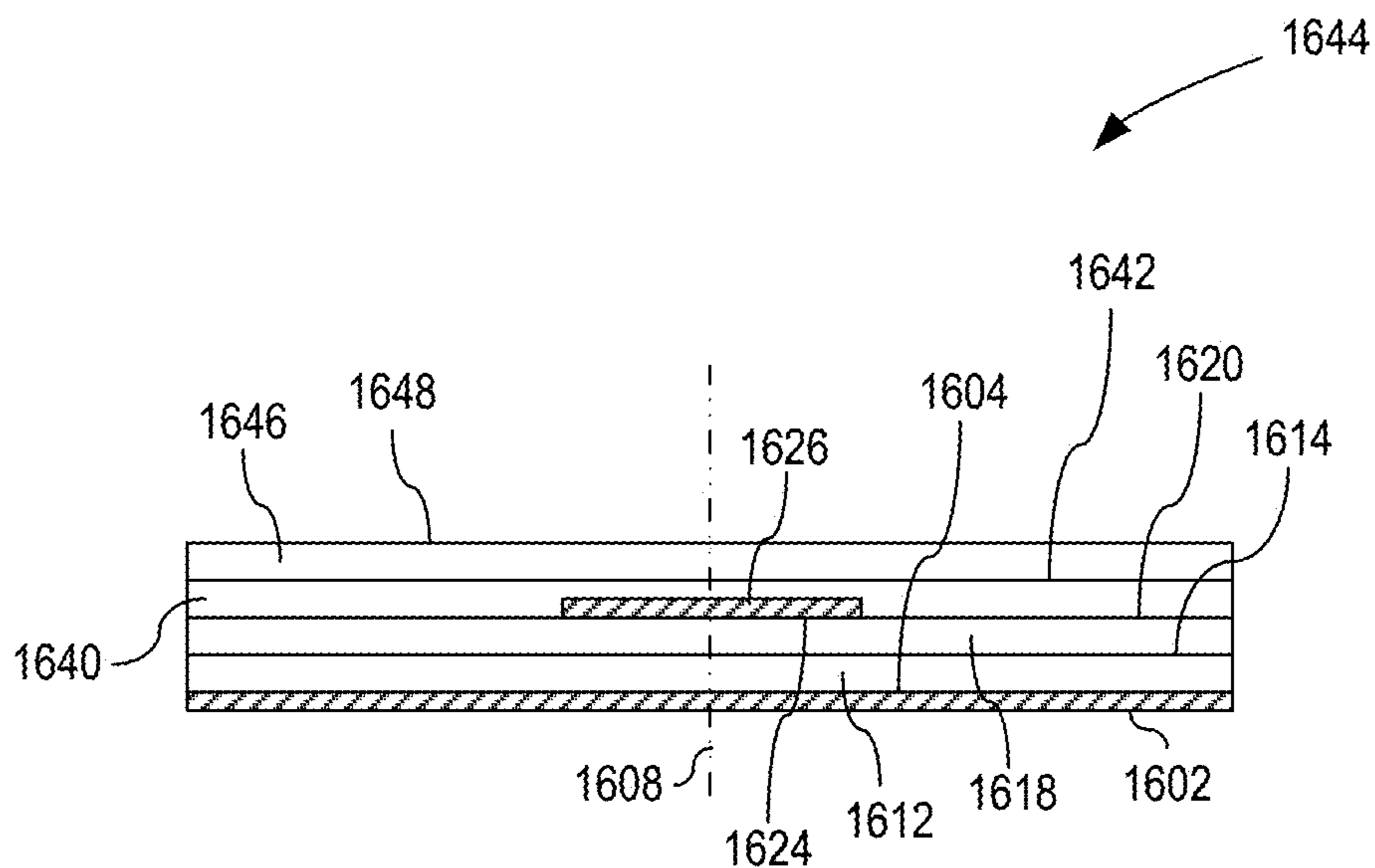


FIG. 16F

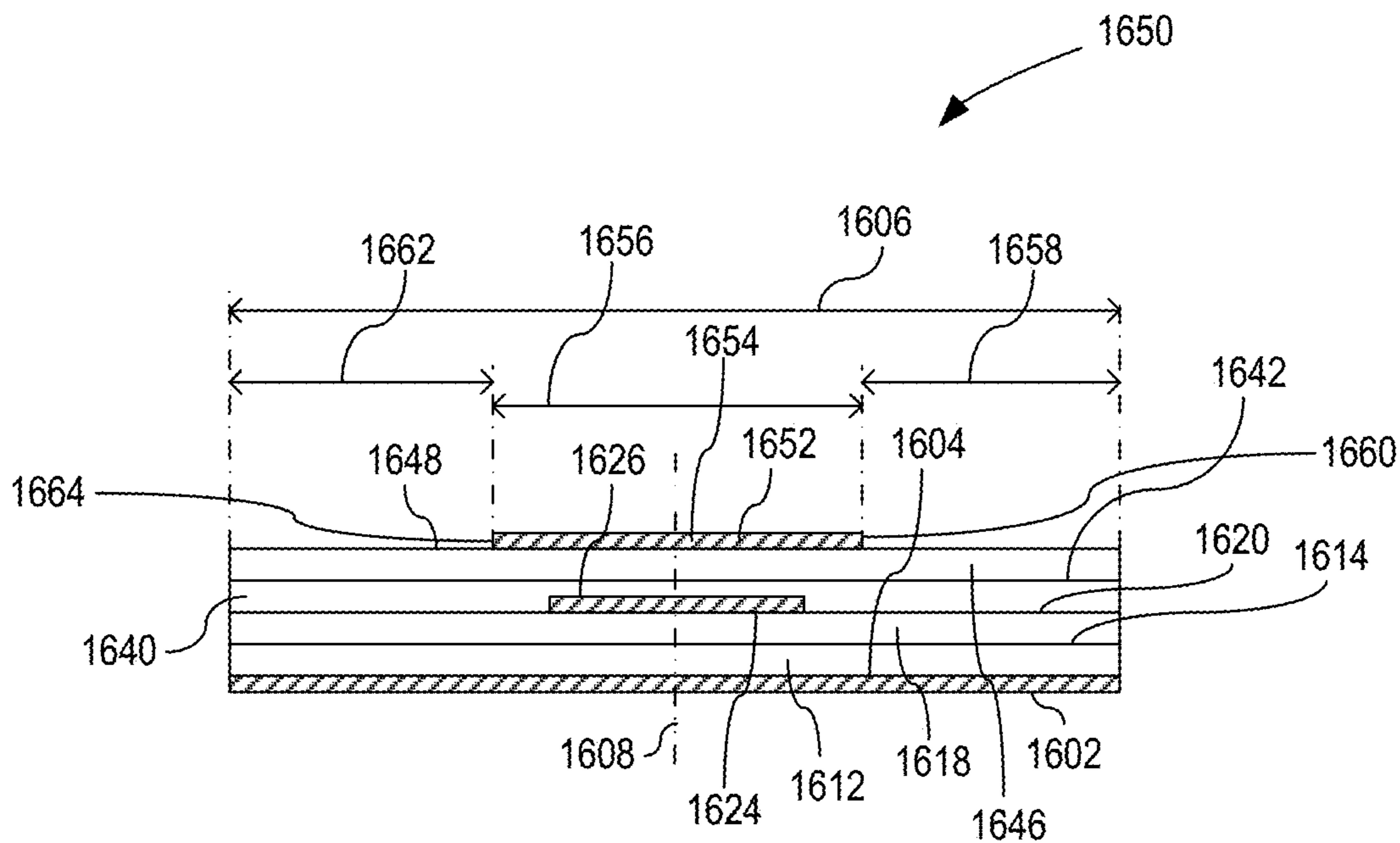


FIG. 16G

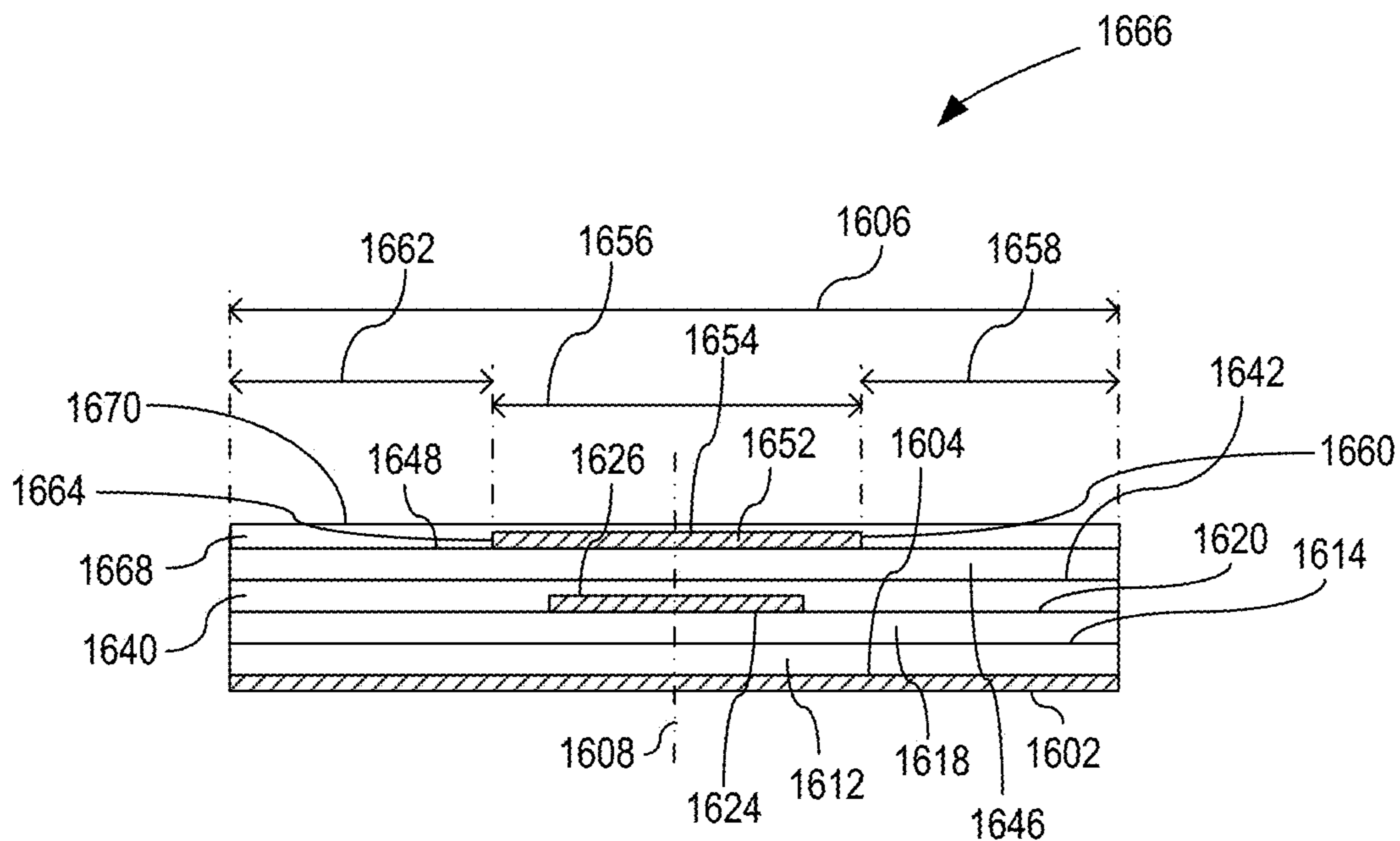


FIG. 16H

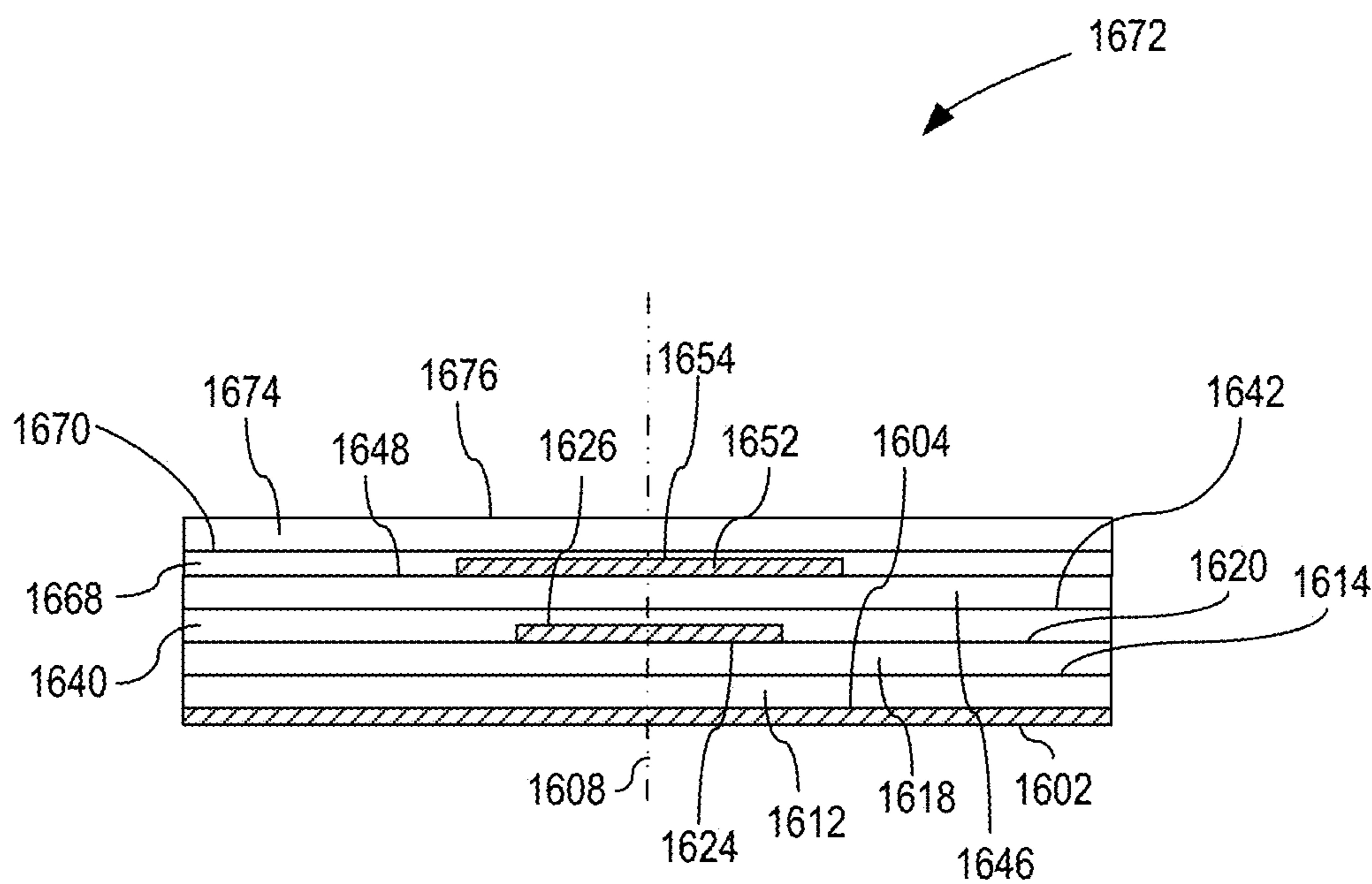


FIG. 16I

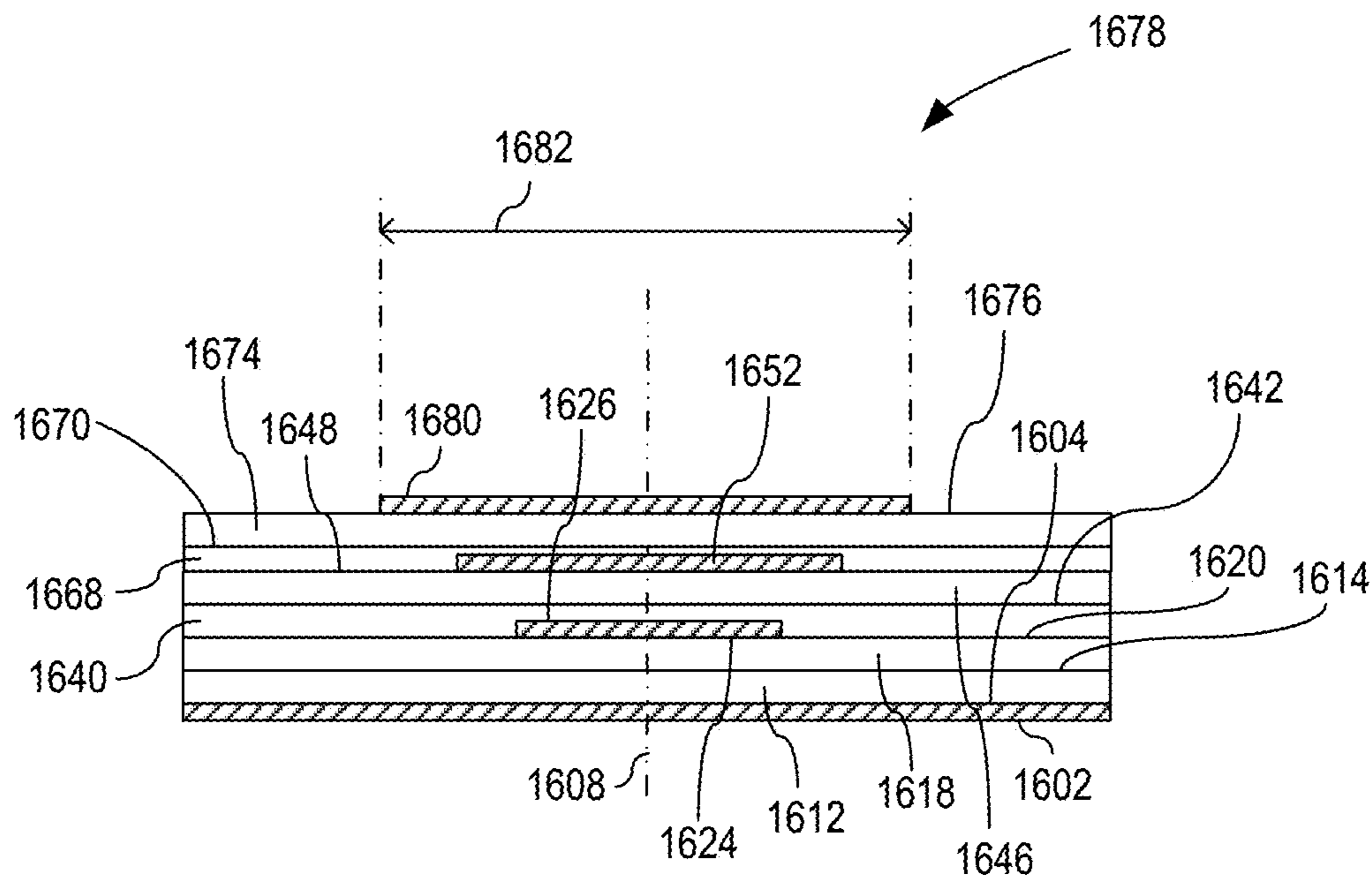


FIG. 16J

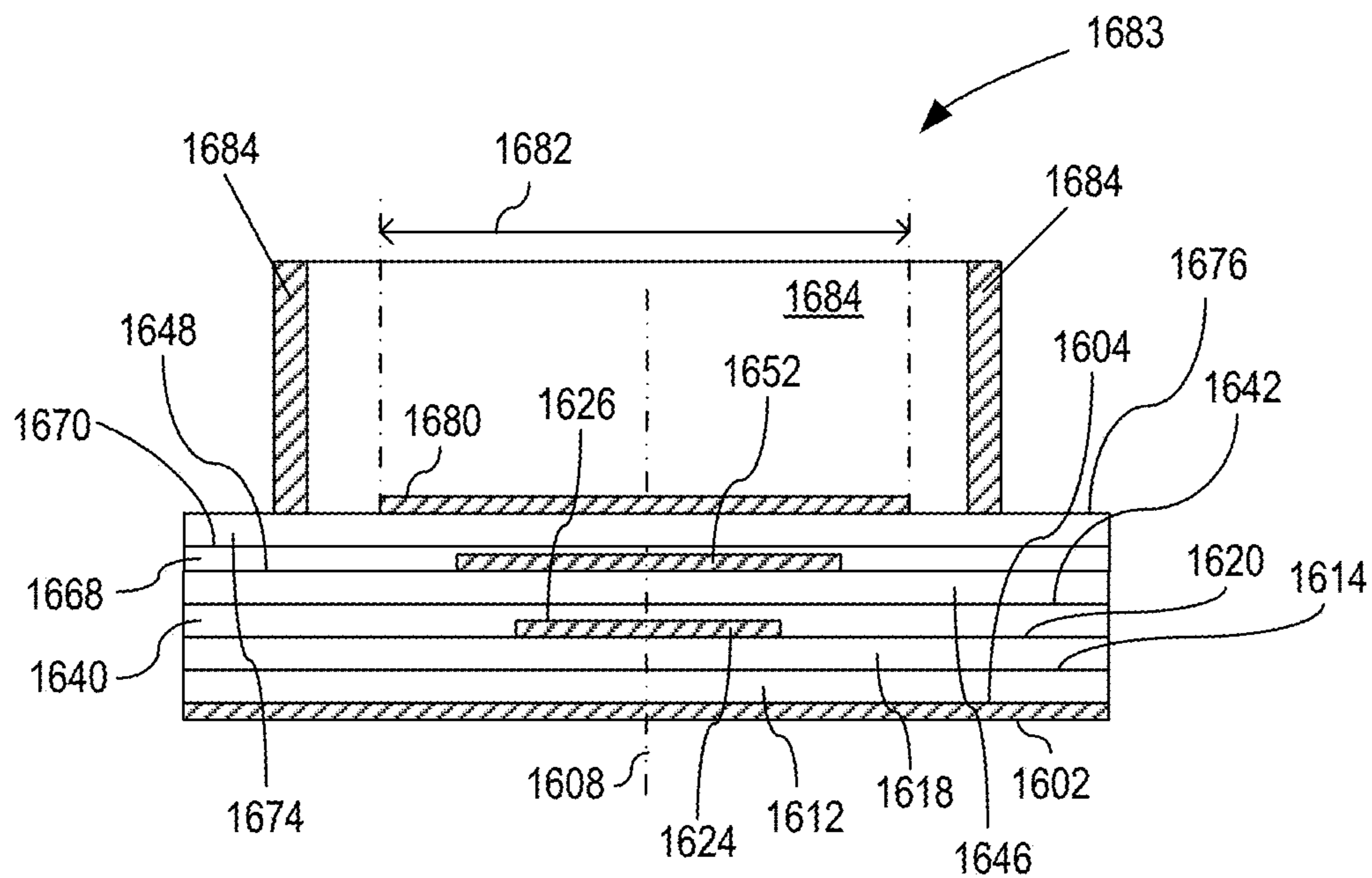


FIG. 16K

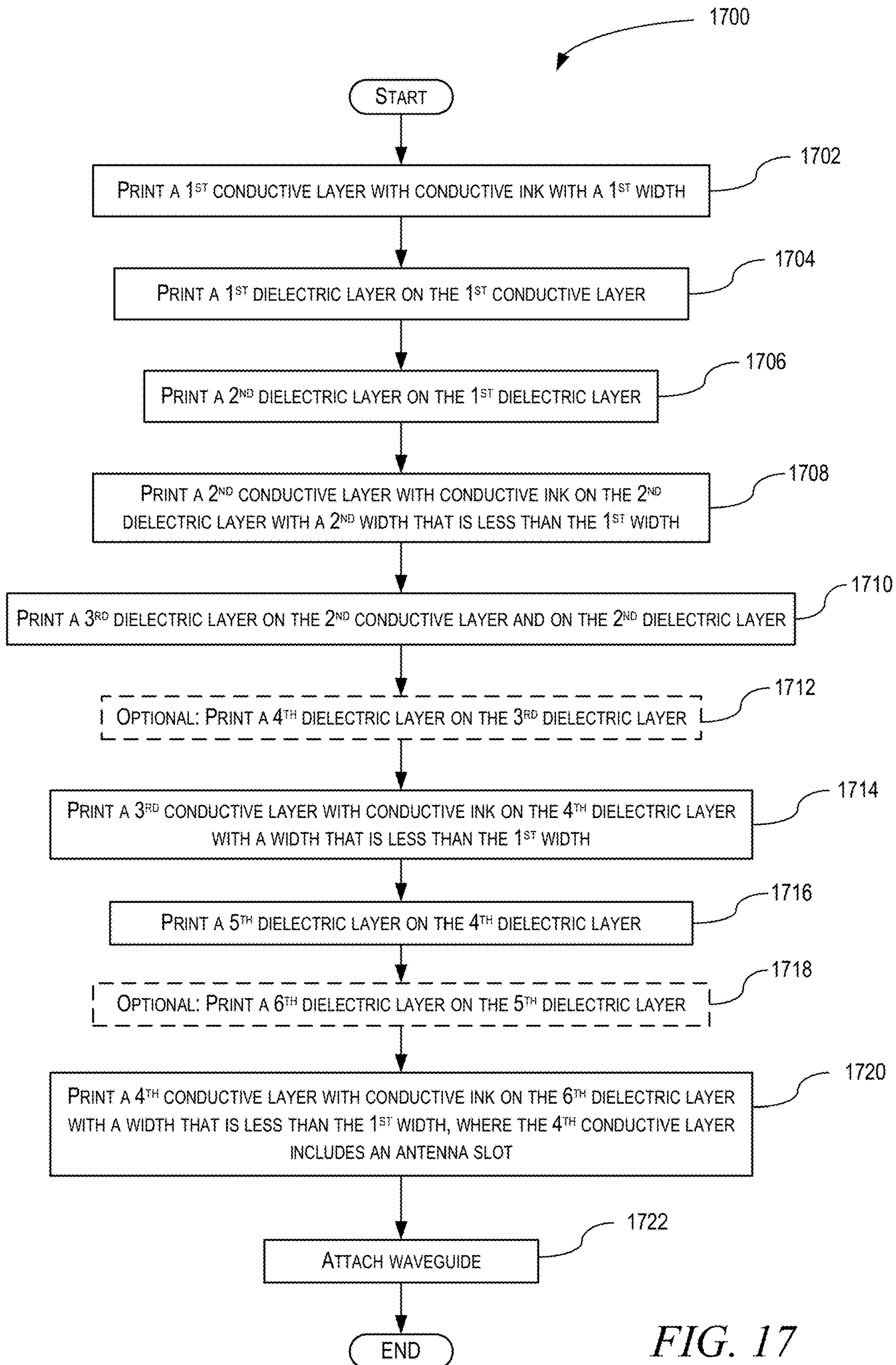


FIG. 17

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## APERTURE-COUPLED MICROSTRIP-TO-WAVEGUIDE TRANSITIONS

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to U.S. patent application Ser. No. 16/111,778, entitled “CONFORMAL ANTENNA WITH ENHANCED CIRCULAR POLARIZATION,” filed on Aug. 24, 2018, to inventor John E. Rogers, and U.S. patent application Ser. No. 16/111,930, entitled “WAVEGUIDE-FED PLANAR ANTENNA ARRAY WITH ENHANCED CIRCULAR POLARIZATION,” filed on Aug. 24, 2018, to inventor John E. Rogers, both of which applications are incorporated by reference herein in their entireties.

### BACKGROUND

#### 1. Field

The present disclosure is related to waveguide transitions, and more specifically, to microstrip-to-waveguide transitions.

#### 2. Related Art

At present, waveguides are used in many RF applications for low-loss signal propagation; however, they are generally not directly compatible with surface-mount device (“SMD”) RF electronics. Known approaches are to utilize waveguide-to-coax adapters for first transitioning from a waveguide to the electronics-compatible coax cable and then utilizing a coax-to-RF board adapter. Unfortunately, existing waveguide-to-coax adapters do not mate well with RF boards because they are typically bulky devices that include waveguide tubing, flanges and a combination of a coaxial probe assembly with coaxial adapter and connection hardware to connect the coaxial adapter to the RF board. As such, at present, known waveguide-to-coax adapters have size, weight, and power (“SWaP”) characteristics and costs that are not compatible with low-cost and conformal RF applications.

As such, there is a need for a new microstrip-to-waveguide transition that addresses one or more of these issues.

### SUMMARY

Disclosed is an aperture coupled microstrip-to-waveguide transition (“ACMWT”). The ACMWT includes a plurality of dielectric layers forming a dielectric structure and an inner conductor formed within the dielectric structure. The plurality of dielectric layers includes a top dielectric layer that has a top surface. The ACMWT further includes a patch antenna element (“PAE”) formed on the top surface, a bottom conductor, an antenna slot within the PAE, a coupling element (“CE”) formed within the dielectric structure between the PAE and inner conductor, and a waveguide. The waveguide includes at least one waveguide wall and a waveguide backend, where the waveguide backend has a waveguide backend surface that is a portion of the top surface of the top dielectric layer and where the waveguide backend surface and the at least one waveguide wall form a waveguide cavity within the waveguide. The PAE is a conductor and is located within the waveguide cavity at the waveguide backend surface and the ACMWT is configured

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to support a transverse electromagnetic (“TEM”) signal within the dielectric structure and a transverse electric (“TE”) signal and a transverse magnetic (“TM”) signal within the waveguide.

Also disclosed is a method for fabricating the ACMWT utilizing a lamination process. The method includes patterning a first conductive layer on a bottom surface of a first dielectric layer to produce a bottom conductor and patterning a second conductive layer on a top surface of a second dielectric layer to produce an inner conductor. The first dielectric layer includes a top surface and the second dielectric layer includes a bottom surface. The method then includes laminating the bottom surface of the second dielectric layer to the top surface of the first dielectric layer and patterning a third conductive layer on a top surface of a third dielectric layer to produce a PAE with an antenna slot. The third dielectric layer includes a bottom surface. The method then includes patterning a fourth conductive layer on a top surface of a fourth dielectric layer to produce a CE, where the fourth dielectric layer includes a bottom surface, laminating the bottom surface of the fourth dielectric layer to the top surface of the second dielectric layer to produce a second combination, and laminating the bottom surface of the third dielectric layer to the top surface of the fourth dielectric layer to produce a composite laminated structure. The composite laminated structure is a dielectric structure. The method then includes attaching a waveguide wall to the composite laminated structure.

Further disclosed is a method for fabricating the ACMWT utilizing a three-dimensional (“3-D”) additive printing process. The method includes printing a first conductive layer having a top surface and a first width. The first width has a first center and the first conductive layer is a bottom layer configured as a reference ground plane. The method then includes printing a first dielectric layer on the top surface of the first conductive layer, where the first dielectric layer has a top surface, printing a second dielectric layer on the top surface of the first dielectric layer, where the second dielectric layer has a top surface, and printing a second conductive layer on the top surface of the second dielectric layer. The second conductive layer has a top surface and a second width, the second width is less than the first width, and the second conductive layer is an inner conductor. The method then includes printing a third dielectric layer on the top surface of the second conductive layer and on the top surface of the second dielectric layer, where the third dielectric layer has a top surface, and printing a third conductive layer on the top surface of the fourth third dielectric layer. The third conductive layer has a top surface and a third width, the third width is less than the first width, and the third conductive layer is a CE. The method then includes printing a fourth dielectric layer on the top surface of the third conductive layer and on the top surface of the third dielectric layer, where the fourth dielectric layer has a top surface, and printing a fourth conductive layer on the top surface of the fourth dielectric layer to produce a PAE with an antenna slot. The fourth conductive layer has a fourth width, the fourth width is less than the first width, and the fourth conductive layer includes the antenna slot within the fourth conductive layer that exposes the top surface of the fourth dielectric layer through the fourth conductive layer. The method then includes attaching the waveguide wall to the fourth dielectric layer.

Other devices, apparatuses, systems, methods, features, and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that

all such additional devices, apparatuses, systems, methods, features, and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

#### BRIEF DESCRIPTION OF THE FIGURES

The invention may be better understood by referring to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. In the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. 1 is a perspective cross-sectional view of an example of an implementation of an aperture coupled microstrip-to-waveguide transition (“ACMWT”) in accordance with the present disclosure.

FIG. 2 is a top view of the ACMWT in accordance with the present disclosure.

FIG. 3 is a top view of an example of another implementation of the ACMWT in accordance with the present disclosure.

FIG. 4 is a cross-sectional front-view of an example of an implementation of the ACMWT (shown in FIG. 1) in accordance with the present disclosure.

FIG. 5 is a cross-sectional front-view of an example of another implementation of the ACMWT (shown in FIG. 1) in accordance with the present disclosure.

FIG. 6 is a cross-sectional front-view of an example of yet another implementation of the ACMWT (shown in FIG. 1) in accordance with the present disclosure.

FIG. 7 is a cross-sectional side-view of the ACMWT, shown in FIG. 5, in accordance with the present disclosure.

FIG. 8A is a cross-sectional front-view of an example of still another implementation of the ACMWT in accordance with the present disclosure.

FIG. 8B is a cross-sectional side-view of the ACMWT, shown in FIG. 8A, in accordance with the present disclosure.

FIG. 9A is a cross-sectional front-view of an example of yet another implementation of the ACMWT in accordance with the present disclosure.

FIG. 9B is a cross-sectional side-view of the ACMWT, shown in FIG. 9A, in accordance with the present disclosure.

FIG. 9C is a top view of the ACMWT, shown in FIGS. 9A and 9B, in accordance with the present disclosure.

FIG. 10 is a zoomed-in view of the PAE and antenna slot within the ACMWT, shown in FIG. 1, in accordance with the present disclosure.

FIG. 11 is a cross-sectional view along a cutting plane showing an inner conductor running along the ACMWT length in accordance with the present disclosure.

FIG. 12 is a cross-sectional view along a cutting plane showing a CE in accordance with the present disclosure.

FIG. 13 is a cross-sectional view along a cutting plane showing an example of an implementation of the single cavity in accordance with the present disclosure.

FIG. 14A is a cross-sectional view of a first section of the ACMWT in accordance with the present disclosure.

FIG. 14B is a cross-sectional view of a second section of the ACMWT in accordance with the present disclosure.

FIG. 14C is a cross-sectional view of a first combination of the first section and the second section of the ACMWT in accordance with the present disclosure.

FIG. 14D is a cross-sectional view of a third section of the ACMWT in accordance with the present disclosure.

FIG. 14E is a cross-sectional view of a fourth section of the ACMWT is shown in accordance with the present disclosure.

FIG. 14F is a cross-sectional view of a second combination of the first combination and the fourth section of the ACMWT in accordance with the present disclosure.

FIG. 14G is a cross-sectional view of a composite laminated structure that includes the second combination and the third section of the ACMWT in accordance with the present disclosure.

FIG. 14H is a cross-sectional view of a combined structure of the ACMWT in accordance with the present disclosure.

FIG. 15 is a flowchart of an example implementation of a method for fabricating the ACMWT utilizing a lamination process in accordance with the present disclosure.

FIG. 16A is a cross-sectional view of first section of the ACMWT in accordance with the present disclosure.

FIG. 16B is a cross-sectional view of a first combination of the first section with a printed first dielectric layer in accordance with the present disclosure.

FIG. 16C is a cross-sectional view of a second combination of the first combination with a printed second dielectric layer in accordance with the present disclosure.

FIG. 16D is a cross-sectional view of a third combination of the second combination with a printed second conductive layer in accordance with the present disclosure.

FIG. 16E is a cross-sectional view of a fourth combination of the third combination with a printed third dielectric layer in accordance with the present disclosure.

FIG. 16F is a cross-sectional view of a fifth combination in accordance with the present disclosure.

FIG. 16G is a cross-sectional view of a sixth combination in accordance with the present disclosure.

FIG. 16H is a cross-sectional view of a seventh combination of the sixth combination with a printed fifth dielectric layer in accordance with the present disclosure.

FIG. 16I is a cross-sectional view of an eighth combination of the seventh combination with a printed sixth dielectric layer in accordance with the present disclosure.

FIG. 16J is a cross-sectional view of a composite printed structure of the seventh combination with a printed fourth conductive layer in accordance with the present disclosure.

FIG. 16K is a cross-sectional view of a combined printed structure of the ACMWT in accordance with the present disclosure.

FIG. 17 is a flowchart of an example implementation of a method for fabricating the ACMWT utilizing a three-dimensional (“3-D”) additive printing process in accordance with the present disclosure.

#### DETAILED DESCRIPTION

An aperture coupled microstrip-to-waveguide transition (“ACMWT”) is disclosed. The ACMWT includes a plurality of dielectric layers forming a dielectric structure and an inner conductor formed within the dielectric structure. The plurality of dielectric layers includes a top dielectric layer that has a top surface. The ACMWT further includes a patch antenna element (“PAE”) formed on the top surface, a bottom conductor, an antenna slot within the PAE, a coupling element (“CE”) formed within the dielectric structure between the PAE and inner conductor, and a waveguide. The waveguide includes at least one waveguide wall and a waveguide backend, where the waveguide backend has a waveguide backend surface that is a portion of the top surface of the top dielectric layer and where the waveguide

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backend surface and the at least one waveguide wall form a waveguide cavity within the waveguide. The PAE is a conductor and is located within the waveguide cavity at the waveguide backend surface and the ACMWT is configured to support a transverse electromagnetic (“TEM”) signal within the dielectric structure and a transverse electric (“TE”) signal and a transverse magnetic (“TM”) signal within the waveguide.

Also disclosed is a method for fabricating the ACMWT utilizing a lamination process. The method includes patterning a first conductive layer on a bottom surface of a first dielectric layer to produce a bottom conductor and patterning a second conductive layer on a top surface of a second dielectric layer to produce an inner conductor. The first dielectric layer includes a top surface and the second dielectric layer includes a bottom surface. The method then includes laminating the bottom surface of the second dielectric layer to the top surface of the first dielectric layer and patterning a third conductive layer on a top surface of a third dielectric layer to produce a PAE with an antenna slot. The third dielectric layer includes a bottom surface. The method then includes patterning a fourth conductive layer on a top surface of a fourth dielectric layer to produce a CE, where the fourth dielectric layer includes a bottom surface, laminating the bottom surface of the fourth dielectric layer to the top surface of the second dielectric layer to produce a second combination, and laminating the bottom surface of the third dielectric layer to the top surface of the fourth dielectric layer to produce a composite laminated structure. The composite laminated structure is a dielectric structure. The method then includes attaching a waveguide wall to the composite laminated structure.

Further disclosed is a method for fabricating the ACMWT utilizing a three-dimensional (“3-D”) additive printing process. The method includes printing a first conductive layer having a top surface and a first width. The first width has a first center and the first conductive layer is a bottom layer configured as a reference ground plane. The method then includes printing a first dielectric layer on the top surface of the first conductive layer, where the first dielectric layer has a top surface, printing a second dielectric layer on the top surface of the first dielectric layer, where the second dielectric layer has a top surface, and printing a second conductive layer on the top surface of the second dielectric layer. The second conductive layer has a top surface and a second width, the second width is less than the first width, and the second conductive layer is an inner conductor. The method then includes printing a third dielectric layer on the top surface of the second conductive layer and on the top surface of the second dielectric layer, where the third dielectric layer has a top surface, and printing a third conductive layer on the top surface of the fourth third dielectric layer. The third conductive layer has a top surface and a third width, the third width is less than the first width, and the third conductive layer is a CE. The method then includes printing a fourth dielectric layer on the top surface of the third conductive layer and on the top surface of the third dielectric layer, where the fourth dielectric layer has a top surface, and printing a fourth conductive layer on the top surface of the fourth dielectric layer to produce a PAE with an antenna slot. The fourth conductive layer has a fourth width, the fourth width is less than the first width, and the fourth conductive layer includes the antenna slot within the fourth conductive layer that exposes the top surface of the fourth dielectric layer through the fourth conductive layer. The method then includes attaching the waveguide wall to the fourth dielectric layer.

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More specifically, in FIG. 1, a perspective cross-sectional view of an example of an implementation of the ACMWT **100** is shown in accordance with the present disclosure. The ACMWT **100** includes a plurality of dielectric layers **102** forming a dielectric structure **104** and an inner conductor **106** formed within the dielectric structure **104**. The plurality of dielectric layers **102** includes a top dielectric layer **108** that has a top surface **110**. The ACMWT **100** further includes a PAE (not shown) formed on the top surface **110**, a bottom conductor **112**, an antenna slot (not shown) within the PAE, an optional CE (not shown) formed within the dielectric structure **104**, and a waveguide **114**. The waveguide **114** includes at least one waveguide wall **116** and a waveguide backend **118**, where the waveguide backend **118** has a waveguide backend surface (not shown) that is a portion of the top surface **110** of the top dielectric layer **108** and where the waveguide backend surface and the at least one waveguide wall **116** form a waveguide cavity **120** within the waveguide **114**. The PAE is a conductor and is located within the waveguide cavity **120** at the waveguide backend surface and the ACMWT **100** is configured to support an input TEM signal **122** within the dielectric structure **104**.

In this example, the inner conductor **106** extends along a length of the along an X-axis **124** to a position located below the PAE within the waveguide **114**. The dielectric structure **104** has a dielectric structure width **126** along a Y-axis **128** and the waveguide **114** extends outward from the waveguide backend **118** at the top surface **110** of the top dielectric layer **108** in direction along a Z-axis **130**.

Furthermore, in this example, the ACMWT **100** may also include CE (not shown), at least one cavity (not shown), or both. The inner conductor **106**, CE, and the optional at least one cavity are formed within the dielectric structure **104**, the PAE is formed on the waveguide backend surface, and the antenna slot is formed within the PAE. Moreover, the bottom conductor **112** is a conductor and is located below the dielectric structure **104** and the PAE is also a conductor. The antenna slot **204** is angled cut along the PAE and is angled with respect to the inner conductor **106**. The antenna slot allows the top surface **110** to be exposed through the PAE. As such, the waveguide **114** is in signal communication with the inner conductor **106**.

The inner conductor **106** is either a radio frequency (“RF”) microstrip or stripline and the inner conductor **106**, bottom conductor **112**, PAE, CE, and at least one waveguide wall **116** may be metal conductors. The bottom conductor **112** acts as a lower reference ground plane that may be, for example, constructed of electroplated copper, while the inner conductor **106**, PAE, and optional CE may also be constructed of electroplated copper or printed silver ink. Additionally, the at least one waveguide wall **116** may be constructed of aluminum.

In an example of operation, the ACMWT **100** is configured to receive an input signal **132** that is transmitted through the waveguide **114** along the negative direction of the Z-axis **130** and, in response, produce the input TEM signal **122** that is transmitted along the inner conductor **106** along the negative direction of the X-axis **124**. Specifically, the input signal **132** propagates along a length of the waveguide **114** towards the waveguide backend surface (that is part of the top surface **110**) where the combined PAE and angled antenna slot (herein antenna slot) are located. Once the input signal **132** reaches the combined PAE and antenna slot, electromagnetic coupling occurs between the combination of the PAE with the antenna slot, optional CE, and the inner conductor **106** to produce the Input TEM signal **122** that is propagated along the inner conductor **106**.



In this example, it is appreciated by those of ordinary skill in the art that the electromagnetic characteristics of the input TEM signal **122** are determined by the geometry (or shape), dimensions (e.g., radius, thickness), and position of the PAE along the top surface **110**, the geometry and dimensions (e.g., slot length and slot width) of the antenna slot within the PAE, the position of inner conductor in relation to the position of the PAE, the geometry and dimensions (e.g., length and width) of the CE, and the position of the optional CE with regards to the position of the PAE and the position of the inner conductor **106**.

It is also appreciated by those of ordinary skill in the art that the ACMWT **100** is a reciprocal device because it is a passive device that only contains isotropic materials. In this example, the ACMWT **100** includes a first port **134** at an opening of the waveguide cavity **120** that allows TE signals and TM signals to propagate along the waveguide. The ACMWT **100** further includes a second port **136** within the dielectric structure **104** that allows TEM signals to propagate between the inner conductor **106** and bottom conductor **112**. As such, the transmission of a signal between the two ports **134** and **136** does not depend on the direction of propagation of the signal. Specifically, as described earlier, an input signal **132** injected into the first port **134** at the waveguide **114** produces the input TEM signal **122** at the second port **136**. Similarly, an output TEM signal **138** injected into the second port **136** produces the output signal **140** at the first port **134**.

In this example, the inner conductor **106** is located within or on a middle dielectric layer (not shown) and the optional CE is located between the inner conductor **106** and the combination of the PAE with the antenna slot within a dielectric layer below the top dielectric layer **108** and above the middle dielectric layer. Based on the fabrication method utilized in producing the ACMWT **100**, it will be shown in this disclosure that the middle dielectric layer may be a dielectric layer from the plurality of dielectric layers **102** or a dielectric layer formed from an adhesive layer of the plurality of adhesive layers, or combination of both.

In this example, a first cutting plane A-A' **142** and a second cutting plane B-B' **144** are shown looking into the ACMWT **100** at different angles. The first cutting plane A-A' **142** cuts through the dielectric structure **104** at a location approximately equal to half of a stack-up height **146** (i.e., at approximately the location of the inner conductor **106**) and looking into a direction along the X-axis **124**. The second cutting plane B-B' **144** cuts through the dielectric structure **104** at an approximate half-point of the location of the waveguide **114** along the top surface **110** of the top dielectric layer **108** and looking into a negative direction along the Z-axis **130**.

It is appreciated by those of ordinary skill in the art that the circuits, components, modules, and/or devices of, or associated with, the ACMWT **100** are described as being in signal communication with each other, where signal communication refers to any type of communication and/or connection between the circuits, components, modules, and/or devices that allows a circuit, component, module, and/or device to pass and/or receive signals and/or information from another circuit, component, module, and/or device. The communication and/or connection may be along any signal path between the circuits, components, modules, and/or devices that allows signals and/or information to pass from one circuit, component, module, and/or device to another and includes wireless or wired signal paths. The signal paths may be physical, such as, for example, conductive wires, electromagnetic wave guides, cables, attached

and/or electromagnetic or mechanically coupled terminals, semi-conductive or dielectric materials or devices, or other similar physical connections or couplings. Additionally, signal paths may be non-physical such as free-space (in the case of electromagnetic propagation) or information paths through digital components where communication information is passed from one circuit, component, module, and/or device to another in varying digital formats without passing through a direct electromagnetic connection.

In this example, the dielectric structure **104** may be constructed utilizing a lamination process in accordance with the present disclosure. This lamination process includes utilizing a plurality of adhesive films (also referred to as adhesive film layers or adhesive layers), or other similar type of dielectric adhesive material, to bond the dielectric layers **102** together to form the dielectric structure **104** with a lamination process that will be described later within this disclosure.

In this example, each dielectric layer, of the plurality of dielectric layers **102**, may be an RF dielectric material and the inner conductor **106** may be a RF microstrip conductor or stripline conductor. Furthermore, in this example, if the optional CE is present, the plurality of dielectric layers **102** may include four (4) dielectric layers and the plurality of adhesive layers may include three (3) adhesive layers; however, this may vary based on the design of the ACMWT **100**. It is appreciated that in this example, each of the three adhesive layers act as a dielectric with different dielectric properties than the other dielectric layers in plurality of dielectric layers **102**.

The CE may be a conductive element such as a notch that extends outward from the inner conductor **106**. The inner conductor **106** may be located at a predetermined center position within the dielectric structure **104**. In this example, the center position is equal to approximately half of the stack-up height **146** along the Z-axis **130**. Moreover, the inner conductor **106** may also have an inner conductor center that is located at a second position within the dielectric structure **104** that is approximately at a second center position that is equal to approximately half of the dielectric structure width **126**. Furthermore, as will be shown later within this disclosure, the CE may be an approximately rectangular like conductive strip that is located below a combination of the PAE and slot antenna and top dielectric layer **108**, and above the inner conductor **106**. The length of the CE may extend outward from a width of the inner conductor **106** at a predetermined angle. As an example, the dielectric laminate material may be constructed of Piralux® flexible circuit materials produced by E. I. du Pont de Nemours and Company of Wilmington, Del.

Alternatively, the dielectric structure **104** may be constructed utilizing a three-dimensional (“3-D”) additive printing process. In this example, each dielectric layer (of the dielectric structure **104**) may be constructed by printing (or “patterning”), which includes successively printing dielectric layers with dielectric ink and printing conductive layers with conductive ink. In these examples, each dielectric layer (of the dielectric structure **104**) may have a thickness that is approximately equal 10 mils. The bottom conductor **112**, inner conductor **106**, optional CE, and PAE may have a thickness that is, for example, approximately equal to 0.7 mils (i.e., about 18 micrometers). For purposes of illustration, in this example, the dielectric structure **104** may include four (4) dielectric layers; again, this may vary based on the design of the ACMWT **100**. In this example, there

would not be any adhesive layers present since this process utilizes 3-D printing instead of lamination for producing the dielectric structure.

While not shown, based on the design of the ACMWT **100**, an optional rigid surface layer may be placed on the top surface **110** that covers the top dielectric layer **108** and is physically attached to the waveguide **114** at or near the waveguide backend **118**. If present, the optional rigid surface layer adds physical strength and rigidity to the waveguide **114** allowing it to interface with an external waveguide (not shown) without causing physical damage to the ACMWT **100**. As an example, the optional rigid surface layer may be thick enough to incorporate the waveguide **114** within the optional rigid surface layer and may include screw holes around an opening of waveguide cavity **120** to attach the waveguide **114** and optional rigid surface layer to a flange of an external waveguide (not shown). Based on the design of the optional rigid surface layer, the optional rigid surface layer may be constructed of metal, plastics, or other rigid materials.

In FIG. **2**, a top view of the ACMWT **100** is shown in accordance with the present disclosure. In this view, the PAE **200** is shown located on the waveguide backend surface **202** within the waveguide cavity **120** of the waveguide **114**. As discussed earlier, the waveguide backend surface **202** is part of the top surface **110** that is located within the waveguide cavity **120**. The antenna slot **204** is shown cut along and through the PAE **200**. In this example, the waveguide **114** is shown to be a rectangular waveguide having a waveguide width **206** and waveguide height **208** that is based on the design of the ACMWT **100**.

In FIG. **3**, a top view of an example of another implementation of the ACMWT **300** is shown in accordance with the present disclosure. This example, the ACMWT **300** has an elliptical waveguide **302** instead of a rectangular waveguide **114**. The elliptical waveguide **302** only has a single waveguide wall **304** that defines the waveguide cavity **306**, which defines the waveguide backend surface **308** along the top surface **110** of the top dielectric layer **108**. The combination of the PAE **200** and antenna slot **204** are still located on the waveguide backend surface **308** within the waveguide cavity **306** at the waveguide backend **118** of the waveguide **302** on the top surface **110** of the top dielectric layer **108**. The elliptical waveguide **302** may be a circular waveguide has a radius **309** that is based on the design of the ACMWT **300**.

It is appreciated by those of ordinary skill in the art that the waveguide (either rectangular waveguide **114** or elliptical waveguide **302**) is a hollow metallic waveguide filled with a homogeneous and isotropic material (usually air). As a result, the waveguide will support TE modes and TM modes of operation, but not a TEM mode as supported by the combination of the dielectric structure **104**, inner conductor **106**, and bottom conductor **112** that forms a microstrip signal path that is an electrical transmission line having a conductive strip (i.e., inner conductor **106**) separated from a reference ground plane (i.e., bottom conductor **112**) by a dielectric layer (i.e., at least a bottom dielectric layer) generally known as a substrate.

In FIG. **4**, a cross-sectional front-view of the ACMWT **100** is shown in accordance with the present disclosure. In this view, the dielectric structure **104**, plurality of dielectric layers **102**, top dielectric layer **108**, bottom dielectric layer **400**, stack-up height **146**, inner conductor **106**, top surface **110**, bottom conductor **112**, waveguide **114**, waveguide wall **116**, waveguide cavity **120**, waveguide backend **118**, waveguide backend surface **202**, PAE **200**, and antenna slot **204**

are shown. In this example, each of the dielectric layers of the plurality of dielectric layers **102** are RF dielectrics.

In this example, the ACMWT **100** is shown to have a center position **402** that may be located at approximately half of the stack-up height **146** and a second center position **404** that is located at approximately half of the dielectric structure width **126**. It is appreciated by those of ordinary skill in the art that while only two (2) dielectric layers are shown in the plurality of dielectric layers **102**, any number greater than two may be utilized for the number of dielectric layers of the plurality of dielectric layers **102**. The inner conductor **106** is also shown to have an inner conductor width **406** that is approximately centered about the second center position **404**. The PAE **200** has a PAE diameter **408** that is wider than the inner conductor width **406**.

In this example, the inner conductor **106** is an RF microstrip or stripline located below the PAE **200** with the antenna slot **204** acting as an aperture coupled antenna feed configured to couple energy to the PAE **200**. In general, the inner conductor width **406** and its respective position below (i.e., the center position **402**) the PAE **200** is predetermined by the design of the ACMWT **100** to approximately match the impedance between the inner conductor **106** and the PAE **200** with the antenna slot **204**.

As such, while the center position **402** is shown in FIG. **4** to be approximately in the center of the stack-up height **146**, it is appreciated by those of ordinary skill in the art that this is an approximation that may vary because the actual center position **402** may be predetermined from the design of the ACMWT **100**. However, for purposes of illustration, the predetermined position is assumed to be generally close to the center position **402** of the stack-up height **146** but it is appreciated that this may vary based on the actual design of the ACMWT **100**. Additionally, while not shown in this view, the antenna slot **204** within the PAE **200** increases the bandwidth of the PAE **200** and also has a predetermined angle along the PAE **200** with respect to the inner conductor **106** to provide circular polarization from the PAE **200** and a predetermined slot width to match the impedance between the inner conductor **106** and the PAE **200**. In general, the bandwidth of the PAE **200** is enhanced by utilizing the aperture coupled feed line from the inner conductor **106** through antenna slot **200** as compared to coupling the inner conductor **106** to the PAE **200** without the presence of the antenna slot **204**.

In this example, the top dielectric layer **108** and bottom dielectric layer **400** are laminated together with an adhesive layer **410** that may be an adhesive film, or other similar type of dielectric adhesive material, to bond the top dielectric layer **108** and bottom dielectric layer **400** together to form the dielectric structure **104** with a lamination process that will be described later within this disclosure. It is appreciated that in this example, that the adhesive layer **410** acts as a dielectric with different dielectric properties than the other dielectric layers in plurality of dielectric layers **102** (i.e., top dielectric layer **108** and bottom dielectric layer **400**).

Alternatively, the dielectric structure **104** may be constructed utilizing a 3-D additive printing process. In this example, each dielectric layer (e.g., top dielectric layer **108** and bottom dielectric layer **400** of the dielectric structure **104**) may be constructed by printing (or "patterning"), which includes successively printing dielectric layers with dielectric ink and printing conductive layers with conductive ink. In these examples, each dielectric layer (of the dielectric structure **104**) may have a thickness that is approximately equal 10 mils. The bottom conductor **112**, inner conductor **106**, and PAE **200** may have a thickness that is, for example,

approximately equal to 0.7 mils (i.e., about 18 micrometers). In this example, there would not be any adhesive layers (e.g., adhesive layer 410) present since this process utilizes 3-D printing instead of lamination for producing the dielectric structure 104.

In this example, a third cutting plane C-C' 412 is shown cutting through dielectric structure 104 at the inner conductor 106 and looking into the ACMWT 100. In this view, the antenna slot 204 is only partially visible because it is located within the PAE 200 that is therefore partially blocked by other parts of the PAE 200 shown in this view.

As discussed earlier, in an example of operation, in one direction, the input signal 132 travels through the waveguide 114 in a direction along the negative Z-axis 130 until it reaches the combination of the PAE 200 and antenna slot 204 on the waveguide backend surface 202 at the waveguide backend 118. Once the input signal 132 reaches the combination of the PAE 200 and antenna slot 204, the resulting electromagnetic field at the combination of the PAE 200 and antenna slot 204 couples to the inner conductor 106 producing the input TEM signal 122 that travels along the inner conductor 106 and bottom conductor 112 in a direction along the negative X-axis 124. In the other direction, the ACMWT 100 is also configured to receive the output TEM signal 138, at the second port 136, that is transmitted by the combination of the inner conductor 106 and bottom conductor 112 along the direction of the X-axis 124 and, in response, produces the output signal 140 that is transmitted along the waveguide 114, at the first port 134, along the direction of the Z-axis 130. In this example, it is appreciated that the waveguide shown in FIG. 4 may be either the rectangular waveguide 114 or the elliptical waveguide 302.

As discussed earlier, the ACMWT 100 may include an optional rigid surface layer that is located on top of the top surface 110 that covers the top dielectric layer 108 and is physically attached to the waveguide 114 at or near the waveguide backend 118. The optional rigid surface layer adds physical strength and rigidity to the waveguide 114 and allows it to interface with an external waveguide (not shown) without causing physical damage to the ACMWT 100. The optional rigid surface layer may have a thickness that is approximately equal to the height of the waveguide 114 so as to incorporate the waveguide 114 within the optional rigid surface layer and may include screw holes (not shown) around an opening of waveguide cavity 120 to attach the waveguide 114 and optional rigid surface layer to a flange of an external waveguide (not shown). Again, based on the design of the optional rigid surface layer, the optional rigid surface layer may be constructed of metal, plastics, or other rigid materials.

In FIG. 5, a cross-sectional front-view of an example of another implementation of the ACMWT 500 is shown in accordance with the present disclosure. In this example, the ACMWT 500 includes a CE 502. The inner conductor 106 is located within or on a middle dielectric layer 504 and the CE 502 is located between the inner conductor 106 and the combination of the PAE 200 with the antenna slot 204 within or on a CE dielectric layer 506 below the top dielectric layer 108 and above the middle dielectric layer 504. Based on the fabrication method utilized in producing the ACMWT 500, the middle dielectric layer 504 may be a dielectric layer from the plurality of dielectric layers 102 or a dielectric layer formed from an adhesive layer of a plurality of adhesive layers 508, or a combination of both. Specifically, in the example shown in FIG. 5, the inner conductor 106 is shown as being located with an adhesive layer 510 (of the plurality of adhesive layers 508) on top of a dielectric layer 512. The

dielectric layer 512 is on top of the combination of the bottom dielectric layer 400 and another adhesive layer 514 from the plurality of adhesive layers 508. In this example, assuming that the inner conductor 106 is exclusively located within the adhesive layer 510 and on top of the dielectric layer 512, the middle dielectric layer 504 would correspond to the adhesive layer 510. If, instead, the inner conductor 106 were exclusively located within the dielectric layer 512, the middle dielectric layer 504 would correspond to the dielectric layer 512. Alternatively, if the inner conductor 106 were located partially with the adhesive layer 510 and the dielectric layer 512, the middle dielectric layer 504 would correspond to a combination of the adhesive layer 510 and dielectric layer 512.

Similarly, based on the fabrication method utilized in producing the ACMWT 500, the CE dielectric layer 506 may be a dielectric layer from the plurality of dielectric layers 102 or a dielectric layer formed from an adhesive layer of a plurality of adhesive layers 508, or a combination of both. Specifically, in the example shown in FIG. 5, the CE 502 is shown as being located with an adhesive layer 516 (of the plurality of adhesive layers 508) on top of a dielectric layer 518. The dielectric layer 518 is on top of the combination of the dielectric layer 512 and adhesive layer 510. In this example, assuming that the CE 502 is exclusively located within the adhesive layer 516 and on top of the dielectric layer 518, the CE dielectric layer 506 would correspond to the adhesive layer 516. If, instead, the CE 502 were exclusively located within the dielectric layer 518, the CE dielectric layer 506 would correspond to the dielectric layer 518. Alternatively, if the CE 502 were located partially with the adhesive layer 516 and the dielectric layer 518, the CE dielectric layer 506 would correspond to a combination of the adhesive layer 516 and dielectric layer 518.

As discussed earlier, in this example, each dielectric layer, of the plurality of dielectric layers 102, may be an RF dielectric material and the inner conductor 106 may be a RF microstrip conductor or stripline conductor. Unlike the previous example, in this example, the plurality of dielectric layers 102 may include four (4) dielectric layers and the plurality of adhesive layers 508 may include three (3) adhesive layers; however, this may vary based on the design of the ACMWT 500. It is appreciated that in this example, each of the three adhesive layers 508 act as a dielectric with different dielectric properties than the other dielectric layers in plurality of dielectric layers 102.

The CE 502 may be a conductive element such as a notch that extends outward from the inner conductor 106. The inner conductor 106 may be located at a predetermined center position within the dielectric structure 104 (e.g., at the center position 402 and second center position 404). Again, in this example, the center position 402 is equal to approximately half of a stack-up height 146 along a Z-axis 130. Moreover, the inner conductor 106 may also have an inner conductor center that is located at a second position within the dielectric structure 104 that is approximately at a second center position 404 that is equal to approximately half of a dielectric structure width 126 of the dielectric structure 104 along a Y-axis 128. Furthermore, the CE 502 may be an approximately rectangular like conductive strip that is located below the combination of the PAE 200 and antenna slot 204 and top dielectric layer 108, and above the inner conductor 106 in or on the CE dielectric layer 506. The CE 502 has a CE length 520 that may extend outward from the inner conductor width 406 at a predetermined angle. In this example, a fourth cutting plane D-D' 522 is shown cutting

through the dielectric structure **104** at the location of the CE **502** and looking into the ACMWT **500**.

As discussed earlier, in an example of operation, in one direction, the input signal **132** travels through the waveguide **114** in a direction along the negative Z-axis **130** until it reaches the combination of the PAE **200** and antenna slot **204** on the waveguide backend surface **202** at the waveguide backend **118**. Once the input signal **132** reaches the combination of the PAE **200** and antenna slot **204**, the resulting electromagnetic field at the combination of the PAE **200** and antenna slot **204** couples between the PAE **200**, CE **502**, and the inner conductor **106** producing the input TEM signal **122** that travels between the inner conductor **106** and bottom conductor **112** in a direction along the negative X-axis **124**. In the other direction, the ACMWT **500** is also configured to receive the output TEM signal **138**, at the second port **136**, that is injected between the inner conductor **106** and bottom conductor **112** along the direction of the X-axis **124** and, in response, produces the output signal **140** that is transmitted along the waveguide **114**, at the first port **134**, along the direction of the Z-axis **130**. In this example, it is appreciated that the waveguide shown in FIG. **5** may be also either the rectangular waveguide **114** or the elliptical waveguide **302**. It is appreciated by those of ordinary skill in the art that the electromagnetic characteristics of the input TEM signal **122** are determined by the geometry (or shape), dimensions (e.g., radius, thickness), and position of the PAE **200** along the top surface **110**, the geometry and dimensions (e.g., slot length and slot width) of the antenna slot **204** within the PAE **200**, and the position, geometry and dimensions (e.g., length and width) of the CE **502** within the dielectric structure **104**.

Again, in this example, the inner conductor **106** is shown to be located within a middle dielectric layer **504** and the CE **502** is located between the inner conductor **106** and the combination of the PAE **200** with the antenna slot **204** within or on the CE dielectric layer **506** below the top dielectric layer **108** and above the middle dielectric layer **504**. Based on the fabrication method utilized in producing the ACMWT **500**, the middle dielectric layer **504** may be a dielectric layer from the plurality of dielectric layers **102** or a dielectric layer formed from an adhesive layer of the plurality of adhesive layers **508**, or combination of both.

The addition of the CE **502** in the ACMWT **500** decreases the axial ratio and increases the circular polarization bandwidth without increasing the size of an antenna array utilizing the ACMWT **500**.

As discussed earlier, the ACMWT **500** may include an optional rigid surface layer that is located on top of the top surface **110** that covers the top dielectric layer **108** and is physically attached to the waveguide **114** at or near the waveguide backend **118**. The optional rigid surface layer adds physical strength and rigidity to the waveguide **114** and allows it to interface with an external waveguide (not shown) without causing physical damage to the ACMWT **500**. The optional rigid surface layer may have a thickness that is approximately equal to the height of the waveguide **114** so as to incorporate the waveguide **114** within the optional rigid surface layer and may include screw holes (not shown) around an opening of waveguide cavity **120** to attach the waveguide **114** and optional rigid surface layer to a flange of an external waveguide (not shown). Again, based on the design of the optional rigid surface layer, the optional rigid surface layer may be constructed of metal, plastics, or other rigid materials.

Turning to FIG. **6**, a cross-sectional front-view of an example of yet another implementation of the ACMWT **600** is shown in accordance with the present disclosure. Similar

to the example described in relation to FIG. **5**, in this view, the dielectric structure **104**, plurality of dielectric layers **102**, top dielectric layer **108**, bottom dielectric layer **400**, stack-up height **146**, inner conductor **106**, top surface **110**, bottom conductor **112**, waveguide **114**, waveguide wall **116**, waveguide cavity **120**, waveguide backend **118**, waveguide backend surface **202**, CE **502**, PAE **200**, and antenna slot **204** are shown. Again, in this example, each of the dielectric layers of the plurality of dielectric layers **102** are RF dielectrics.

In this example, the ACMWT **600** is again shown to have a center position **402** that may be located at approximately half of the stack-up height **146** and a second center position **404** that is located at approximately half of the dielectric structure width **126** of the dielectric structure **104**.

The difference between this example and the one described in relation to FIG. **5** is that in this example the ACMWT **600** includes a cavity **602** within the ACMWT **600** to improve the electromagnetic performance of the ACMWT **600**. In this example, the cavity **602** may be located within the dielectric structure **104** between the inner conductor **106** and the PAE **200** at the middle dielectric layer **504**, CE dielectric layer **506**, and/or adhesive layer between the middle dielectric layer **504** and CE dielectric layer **506**. The cavity **602** is centered about the inner conductor **106** with a cavity width **604**, which is greater than the inner conductor width **406**. The cavity **602** may also have a cavity height **606** that is greater than or approximately equal to the height of the inner conductor **106**. The cavity **602**, for example, may be filled with air.

In this example, cavity **602** may have a circular perimeter such that the cavity width **604** may be approximately equal to the width of the PAE **200**. Alternatively, the diameter of the cavity (i.e., cavity width **604**) may be more or less than the PAE diameter **408** of the PAE **200**. In general, the cavity width **604** is a predetermined value that is based on the design of the ACMWT **600** such as to enhance and approximately optimize the gain and bandwidth of the CE **502** and PAE **200** with the antenna slot **204**.

As discussed earlier, the ACMWT **600** may include an optional rigid surface layer that is located on top of the top surface **110** that covers the top dielectric layer **108** and is physically attached to the waveguide **114** at or near the waveguide backend **118**. The optional rigid surface layer adds physical strength and rigidity to the waveguide **114** and allows it to interface with an external waveguide (not shown) without causing physical damage to the ACMWT **600**. The optional rigid surface layer may have a thickness that is approximately equal to the height of the waveguide **114** so as to incorporate the waveguide **114** within the optional rigid surface layer and may include screw holes (not shown) around an opening of waveguide cavity **120** to attach the waveguide **114** and optional rigid surface layer to a flange of an external waveguide (not shown). Again, based on the design of the optional rigid surface layer, the optional rigid surface layer may be constructed of metal, plastics, or other rigid materials.

In FIG. **7**, a cross-sectional side-view of the ACMWT **500** (shown in FIG. **5**) is shown in accordance with the present disclosure. In this view, the dielectric structure **104**, plurality of dielectric layers **102**, top dielectric layer **108**, bottom dielectric layer **400**, middle dielectric layer **504**, CE dielectric layer **506**, plurality of adhesive layers **508**, adhesive layer **510**, dielectric layer **512**, adhesive layer **514**, adhesive layer **516**, dielectric layer **518**, stack-up height **146**, inner conductor **106**, top surface **110**, bottom conductor **112**, waveguide **114**, waveguide wall **116**, waveguide cavity **120**, waveguide backend **118**, waveguide backend surface **202**,

center position **402**, first port **134**, second port **136**, CE **502**, PAE **200**, and antenna slot **204** are shown. The PAE **200** has a PAE center **700** located at the center of the PAE **200** and a PAE diameter **702**. The ACMWT **500** also has an ACMWT length **704** that extends from the second port **136** to an end **706** of the ACMWT **500** and the inner conductor **106** has an inner conductor length **708**. In this example the inner conductor length **708** is shown to extend a little past a CE width **710** but without extending beyond the PAE diameter **702**. It is appreciated by those of ordinary skill in the art that the actual end of the inner conductor length **708** is predetermined by the design of the ACMWT **500**.

Turning to FIG. **8A**, a cross-sectional front-view of an example of still another implementation of the ACMWT **800** is shown in accordance with the present disclosure. In this example, the ACMWT **800** includes a rigid surface layer **802** on top surface **110** of the top dielectric layer **108** of the ACMWT **800**. The rigid surface layer **802** covers the top dielectric layer **108** and is physically attached to the waveguide **114** at or near the waveguide backend **118**. In this example, the rigid surface layer **802** adds physical strength and rigidity to the waveguide **114** without causing physical damage to the ACMWT **800**.

As an example, the rigid surface layer **802** may be thick enough to incorporate the waveguide **114** within the optional rigid surface layer **802** and may include screw holes (not shown) around an opening of waveguide cavity **120** to attach the waveguide **114** and the rigid surface layer **802** to a flange of an external waveguide (not shown). Based on the design of the rigid surface layer **802**, the rigid surface layer **802** may be constructed of metal, plastics, or other rigid materials. If the rigid surface layer **802** is fabricated from or includes a metal or other conductive material, the rigid surface layer **802** may act as a ground plane for the waveguide walls **116**. In FIG. **8B**, a cross-sectional side-view of the ACMWT **800** is shown in accordance with the present disclosure.

In FIG. **9A**, a cross-sectional front-view of an example of another implementation of the ACMWT **900** having a rigid surface layer **902** is shown in accordance with the present disclosure. In this example, the rigid surface layer **902** has a height that is approximately equal to the waveguide length **904**. FIG. **9B** is a cross-sectional side-view of the ACMWT **900** in accordance with the present disclosure and FIG. **9C** is a top view of the ACMWT **900** in accordance with the present disclosure. In FIG. **9C**, four screw holes **906** are shown that penetrate into the rigid surface layer **902**. The four screw holes **906** may be utilized to attach an external waveguide flange (not shown) on to the ACMWT **900**. It is appreciated that in this example, the waveguide may be either the rectangular waveguide **114** or elliptical waveguide **302**.

Turning to FIG. **10**, a zoomed-in view of the PAE **200** and antenna slot **204** within the ACMWT **100** are shown in accordance with the present disclosure. In this example, the antenna slot **204** is shown within the PAE **200** at an angle  $\theta$  **1000** with respect to the inner conductor **106** along the second center position **404**. In this example, the antenna slot **204** is shown to be centered about the second center position **404**. The angle  $\theta$  **1000** may be negative or positive. In this example, the PAE **200** is shown to have a circular shape with a radius **1002**. As discussed earlier, the geometry (or shape), dimensions (e.g., radius, thickness), and position of the PAE **200** along the top surface **110** and the geometry and dimensions (e.g., slot length and slot width) of the antenna slot **204** within the PAE **200** determine the electromagnetic characteristics of the radiated output signal **140** or received input TEM signal **122**. Moreover, in this example, the PAE **200** is

circular with the radius **1002** and the antenna slot **204** has a slot length **1004** and slot width **1006**. In this example, the antenna slot **204** may be rectangular in shape. In general, the radius **1002** of the PAE **200** and the slot length **1004** and slot width **1006** are predetermined to enhance and approximately optimize/maximize the either the radiated output signal **140** or the received input TEM signal **122** produced by the CE **502** and PAE **200** (with the antenna slot **204**) at a predetermined operating frequency. It is appreciated by those of ordinary skill in the art that other geometries may also be utilized in the present disclosure without departing from the spirit or principles disclosed herein. In this example, the radius **1002** is equal to half of the PAE diameter (e.g., PAE diameter **408** or PAE diameter **702**).

FIG. **11** is a cross-sectional view along either the first cutting plane A-A' **142** or the third cutting plane C-C' **412** showing the inner conductor **106** running along the ACMWT **500** length (in the direction of the X-axis **124**) in accordance with the present disclosure. In this example, the inner conductor **106** is shown to be within the plurality of dielectric layers **102** in the middle dielectric layer **504** of the dielectric structure **104** between two other dielectric layers (not shown). The inner conductor length **708** of the inner conductor **106** extends from the second port **136** to a location under the PAE **200** that may be approximately at or near the PAE center **700**. In this example, a PAE outline **1100** of the PAE **200** is shown for reference.

FIG. **12** is a cross-sectional view along the fourth cutting plane D-D' **522** showing the CE **502** in accordance with the present disclosure. In this example, the CE **502** is shown as a stub that has the CE length **520** that is approximately orthogonal to the inner conductor length **708** of the inner conductor **106**. In this view, the inner conductor **106** is located within the plurality of dielectric layers **102** below the CE dielectric layer **506**. The inner conductor **106** is located below the CE **502** and is not visible. Moreover, the PAE **200** and antenna slot **204** are located above the CE **502** on the top dielectric layer **108** and are also not visible. As such, in this view, an inner conductor outline **1200** of the inner conductor **106** and the PAE outline **1100** of the PAE **200** are shown for purposes of illustration. The inner conductor outline **1200** is centered about the second center position **404**. In this example, the CE **502** is located below the PAE **200** within the PAE outline **1100** where the CE length **520** is less than or equal to the PAE diameter **702** (i.e., twice the radius **1002**) of the PAE outline **1100** and extends approximately orthogonally from the inner conductor outline **1200**. In general, the CE length **520**, CE width **710**, and angle with respect to the inner conductor **106** are predetermined to enhance and approximately optimize the radiated or received signals (i.e., output signal **140** or input TEM signal **122**) of the combined PAE **200** and antenna slot **204** at a predetermined operating frequency.

In this disclosure, the inner conductor **106**, CE **502**, and PAE **200** are designed to be electrically coupled to one another at a predetermined operating frequency. In an example of operation, in one direction, the output TEM signal **138** inserted into the second port **136** traverses between the inner conductor **106** and bottom conductor **112** (as a TEM mode), then electrically couples through the dielectric structure **104** to the CE **502** where the current of the signal is rotated due to the orientation of CE **502** with respect to the inner conductor **106**. The signal then electrically couples from CE **502** through the dielectric structure **104** to the PAE **200** where the current of the signal further rotates due to the orientation of PAE **200** with respect to CE **502**. The circularly polarized radiated signal is then radiated

into the waveguide cavity **120** and propagated along the waveguide **114** (as either a TE or TM mode) to the output signal **140**. In the opposite direction, the input signal **132** injected into the first port **134** propagates along the waveguide length **904** (as either a TE mode or TM mode) until it reaches the combined PAE **200** and antenna slot **204**. The input signal **132** induces coupling between the combined PAE **200** and antenna slot **204** and inner conductor **106** through the CE **502**. The resulting coupled signal is rotated in the opposite direction and traverses between the inner conductor **106** and bottom conductor **112** (as a TEM mode) towards the second port **136** as the input TEM signal **122**.

FIG. **13** is a cross-sectional view along either the first cutting plane A-A' **142** or the third cutting plane C-C' **412** showing an example of an implementation of the single cavity **602** in accordance with the present disclosure. In this example, the inner conductor **106** is shown to be in the middle dielectric layer **504** of the dielectric structure **104**. The cavity **602** is also shown within the dielectric structure **104** around and above the inner conductor **106**. The cavity **602** has a perimeter **1300** that is circular with a diameter equal to the cavity width **1302**. In this example, the cavity **602** is shown to cut through the middle dielectric layer **504** exposing a top surface **1303** of the dielectric layer below the middle dielectric layer **504**. As in the example shown in FIG. **6**, the cavity **602** is located below the PAE **200** and the CE **502** and around and above the inner conductor **106**. The cavity width **1302** is approximately equal to or less than the PAE diameter (e.g., PAE diameter **408** and **702**). In this example, the cavity **602** is air filled and has the width **1302** and the height **606** occupying the space around the inner conductor **106** and above a top surface **1304** of the inner conductor **106**. The cavity **602** may be adjacent to the sides of the portion of the inner conductor **106**. In general, the cavity width **1302** is a predetermined value that is based on the design of the ACMWT **600** such as to enhance and approximately optimize the gain and bandwidth of the CE **502** and PAE **200** with the antenna slot **204**. While only a single cavity **602** is shown in this example, it is appreciated that in other examples may include multiple cavities within the middle dielectric layer **504**.

Turning to FIGS. **14A-14H**, a method for fabricating the ACMWT (i.e., ACMWT **100**, **300**, **500**, **600**, **800**, and **900**) utilizing a lamination process is shown. Specifically, in FIG. **14A**, a cross-sectional view of a first section **1400** of the ACMWT is shown in accordance with the present disclosure. The first section **1400** of the ACMWT includes a first dielectric layer **1402** with a first conductive layer **1404** patterned on a bottom surface **1406** of the first dielectric layer **1402**, where the first dielectric layer **1402** has a top surface **1408** and bottom surface **1406**. In this example, the first conductive layer **1404** is the bottom conductor (i.e., bottom conductor **112**). In this example, the first conductive layer **1404** may be constructed of a conductive metal such as, for example, electroplated copper or printed silver ink.

In FIG. **14B**, a cross-sectional view of a second section **1410** of the ACMWT is shown in accordance with the present disclosure. The second section **1410** of the ACMWT includes a second dielectric layer **1412** with a second conductive layer **1414** patterned on a top surface **1416** of the second dielectric layer **1412**, where the second dielectric layer **1412** includes a top surface **1416** and bottom surface **1418**. In this example, the second conductive layer **1414** is an inner conductor (i.e., inner conductor **106**) of the ACMWT. In this example, the second conductive layer **1414** may be constructed of a conductive metal such as, for example, electroplated copper or printed silver ink.

In FIG. **14C**, a cross-sectional view of a first combination **1420** of the first section **1400** and the second section **1410** of the ACMWT is shown in accordance with the present disclosure. The first combination **1420** is formed by laminating the bottom surface **1418** of the second dielectric layer **1412** to the top surface **1408** of the first dielectric layer **1402** with a first adhesive layer **1422** that may be an adhesive film.

In FIG. **14D**, a cross-sectional view of a third section **1424** of the ACMWT is shown in accordance with the present disclosure. The third section **1424** of the ACMWT includes a third dielectric layer **1426** with a third conductive layer **1428** patterned on a top surface **1430** of the third dielectric layer **1426**, where the third dielectric layer **1426** also includes a bottom surface **1432**. In this example, the third conductive layer **1428** is the PAE of the ACMWT. In this example, the third conductive layer **1428** may be constructed of a conductive metal such as, for example, electroplated copper or printed silver ink.

In FIG. **14E**, a cross-sectional view of a fourth section **1434** of the ACMWT is shown in accordance with the present disclosure. The fourth section **1434** of the ACMWT includes a fourth dielectric layer **1436** with a fourth conductive layer **1438** patterned on a top surface **1440** of the fourth dielectric layer **1436**, where the fourth dielectric layer **1436** also includes a bottom surface **1442**. In this example, the fourth conductive layer **1438** is a CE (i.e., CE **502**) of the ACMWT. In this example, the fourth conductive layer **1438** may be constructed of a conductive metal such as, for example, electroplated copper or printed silver ink.

In FIG. **14F**, a cross-sectional view of a second combination **1444** of the first combination **1420** and the fourth section **1434** of the ACMWT is shown in accordance with the present disclosure. The second combination **1444** is formed by laminating the bottom surface **1442** of the fourth dielectric layer **1436** to the top surface **1416** of the second dielectric layer **1412** with a second adhesive layer **1446**.

In FIG. **14G**, a cross-sectional view of a composite laminated structure **1448** that includes the second combination **1444** and the third section **1424** of the ACMWT is shown in accordance with the present disclosure. In the composite laminated structure **1448**, the bottom surface **1432** of the third dielectric layer **1426** is laminated on to the top surface **1440** of the fourth dielectric layer **1436** with a third adhesive layer **1450** producing the composite laminated structure **1448** that is also the dielectric structure (e.g., dielectric structure **104**).

In FIG. **14H**, a cross-sectional view of a combined structure **1452** of the ACMWT is shown in accordance with the present disclosure. In this view, the waveguide walls **1454** (e.g., waveguide walls **116** or waveguide wall **304**) are attached to the composite laminated structure **1448** on the top surface **1430** of the third dielectric layer **1426**.

As discussed earlier, the ACMWT may also include laminating a rigid surface layer (not shown) on the top surface **1430** of the third dielectric layer **1426** so as to establish a rigid base for the waveguide walls **1454**. The thickness of this rigid surface layer may vary based on the design of the ACMWT such as a smaller thickness as shown in FIGS. **8A** and **8B** to a thickness that is approximately equal to the waveguide length **904** as shown in FIGS. **9A** through **9C**.

Moreover, as described in relation to FIG. **6**, the ACMWT may include an optional cavity (that may be filled with air) about the second conductive layer **1414** (i.e., the inner conductor **106**). This optional cavity may be formed within the fourth dielectric layer **1436** and/or the second adhesive layer **1446**. In this example, the fourth dielectric layer **1436**

may include sub-sections of the fourth dielectric layer **1436** to produce at least one cavity that may be about (i.e., surround) the second conductive layer **1414**.

In these examples, the first dielectric layer **1402**, second dielectric layer **1412**, third dielectric layer **1426**, and fourth dielectric layer **1436** may be constructed of an RF dielectric material such as, for example, Pyralux®. Moreover, each of these dielectric layers **1402**, **1412**, **1426**, and **1436** may be laminated to each other with first, second, and third adhesive layers **1422**, **1446**, and **1450**, respectively, where each adhesive layer **1422**, **1446**, and **1450** may be an adhesive film, adhesive tape, bonding film, or other adhesive material.

In FIG. **15**, a flowchart is shown of an example implementation of a method **1500** for fabricating the ACMWT utilizing a lamination process in accordance with the present disclosure. The method **1500** is related to the method for fabricating the ACMWT (i.e., ACMWT **100**, **300**, **500**, **600**, **800**, and **900**) utilizing the lamination process described in FIGS. **14A-14H**. The method **1500** starts by patterning **1502** the first conductive layer **1404** on the bottom surface **1406** of the first dielectric layer **1402** to produce a bottom conductor **112** acting as a reference ground plane. The method **1500** additionally includes patterning **1504** the second conductive layer **1414** on a portion of the top surface **1416** of a second dielectric layer **1412** to produce the inner conductor **106**. The method **1500** also includes laminating **1506** the bottom surface **1418** of the second dielectric layer **1412** to the top surface **1408** of the first dielectric layer **1402**. The method **1500** also includes patterning **1508** the third conductive layer **1428** on a portion of the top surface **1430** of the third dielectric layer **1426** to produce the PAE **200** with the antenna slot **204**. The method **1500** additionally includes patterning **1510** the fourth conductive layer **1438** on a portion of the top surface **1440** of the fourth dielectric layer **1436** to produce the CE **502**. The method **1500** further includes laminating **1512** the bottom surface **1442** of the fourth dielectric layer **1436** to the top surface **1416** of the second dielectric layer **1412** to produce the second combination **1444**. The method **1500** further includes laminating **1514** the bottom surface **1432** of the third dielectric layer **1426** to the top surface **1440** of the fourth dielectric layer **1436** to produce the composite laminated structure **1448** that is the dielectric structure (e.g., dielectric structure **104**). The method **1500** then includes attaching **1516** the waveguide to the composite laminated structure **1448**.

In this example, the method **1500** may utilize a sub-method where one or more of the first conductive layer **1404**, second conductive layer **1414**, third conductive layer **1428**, and fourth conductive layer **1438** are formed by a subtractive method (e.g., wet etching, milling, or laser ablation) of electroplated or rolled metals or by an additive method (e.g., printing or deposition) of printed inks or deposited thin-films. The method **1500** then ends.

In FIGS. **16A-16K**, a method for fabricating the ACMWT (i.e., ACMWT **100**, **300**, **500**, **600**, **800**, and **900**) utilizing an additive 3-D printing process is shown.

Specifically, in FIG. **16A**, a cross-sectional view of a first section **1600** of the ACMWT is shown in accordance with the present disclosure. The first section **1600** of the ACMWT includes a printed first conductive layer **1602** with a top surface **1604** and a first width **1606**, where the first width **1606** has a first center **1608**. The printed first conductive layer **1602** is the bottom conductor **112** acting as a reference ground plane.

In FIG. **16B**, a cross-sectional view of a first combination **1610** of the first section **1600** with a printed first dielectric layer **1612** is shown in accordance with the present disclo-

sure. In this example, the printed first dielectric layer **1612** has a top surface **1614** that is printed on the top surface **1604** of the printed first conductive layer **1602**.

In FIG. **16C**, a cross-sectional view of a second combination **1616** of the first combination **1610** with a printed second dielectric layer **1618** is shown in accordance with the present disclosure. In this example, the printed second dielectric layer **1618** has a top surface **1620** and is printed on the top surface **1614** of the first dielectric layer **1612**.

In FIG. **16D**, a cross-sectional view of a third combination **1622** of the second combination **1616** with a printed second conductive layer **1624** is shown in accordance with the present disclosure. Specifically, the printed second conductive layer **1624** has a top surface **1626** and a second width **1628** (that is less than the first width **1606**) that is printed on the top surface **1620** of the second dielectric layer **1618**. The printed second conductive layer **1624** is the inner conductor **106**. In this example, the second width **1628** results in a first gap **1630** at a first end **1632** of the second conductive layer **1624** and a second gap **1634** at a second end **1636** of the second conductive layer **1624**, where the top surface **1620** of the second dielectric layer **1618** is exposed.

In FIG. **16E**, a cross-sectional view of a fourth combination **1638** of the third combination **1622** with a printed third dielectric layer **1640** is shown in accordance with the present disclosure. Specifically, the printed third dielectric layer **1640** is printed on the top surface **1626** of the printed second conductive layer **1624** and the top surface **1620** of the printed second dielectric layer **1618** though the first gap **1630** and second gap **1634**. In this example, the printed third dielectric layer **1640** has a top surface **1642**. Furthermore, in this example, the printed third dielectric layer **1640** may have a height that is greater than or equal to the height of the printed second conductive layer **1624**.

In FIG. **16F**, a cross-sectional view of a fifth combination **1644** is shown in accordance with the present disclosure. The fifth combination **1644** is a combination of the fourth combination **1638** and a printed fourth dielectric layer **1646**. Specifically, the printed fourth dielectric layer **1646** has a top surface **1648** and is printed on the top surface **1642** of the printed third dielectric layer **1640**. It is appreciated by those of ordinary skill in the art that based on the design and thickness of the third dielectric layer **1940**, the fourth dielectric layer **1646** may be optional. Specifically, the distance between the printed second conductive layer **1624** and a soon to be printed third conductive layer (not shown) is a predetermined distance based on the design of the ACMWT. As such, the height of the third dielectric layer **1640** is either equal to this predetermined distance if the fourth dielectric layer **1646** is not utilized or the height of the combination of the third dielectric layer **1640** and the fourth dielectric layer **1646** is equal to the predetermined distance.

In FIG. **16G**, a cross-sectional view of a sixth combination **1650** is shown in accordance with the present disclosure. The sixth combination **1650** is a combination of the fifth combination **1644** and a printed third conductive layer **1652**. The printed third conductive layer **1652** has a top surface **1654** and a third width **1656** (that is less than the first width **1606**) that is printed on the top surface **1648** of the printed fourth dielectric layer **1646**. In this example, the third width **1656** results in a first gap **1658** at a first end **1660** of the printed third conductive layer **1652** and a second gap **1662** at a second end **1664** of the printed third conductive layer **1652**, where the top surface **1648** of the printed fourth dielectric layer **1646** is exposed. The third conductive layer **1652** is a CE (e.g., CE **502**).

In FIG. 16H, a cross-sectional view of a seventh combination 1666 of the sixth combination 1650 with a printed fifth dielectric layer 1668 is shown in accordance with the present disclosure. Specifically, the printed fifth dielectric layer 1668 is printed on the top surface 1654 of the printed third conductive layer 1652 and the top surface 1648 of the printed fourth dielectric layer 1646 though the first gap 1658 and second gap 1662. In this example, the printed fifth dielectric layer 1668 has a top surface 1670. Furthermore, in this example, the printed fifth dielectric layer 1668 may have a height that is greater than or equal to the height of the printed third conductive layer 1652.

In FIG. 16I, a cross-sectional view of an eighth combination 1672 of the seventh combination 1666 with a printed sixth dielectric layer 1674 is shown in accordance with the present disclosure. The printed sixth dielectric layer 1674 has a top surface 1676 and is printed on the top surface 1670 of the printed fifth dielectric layer 1668. It is appreciated by those of ordinary skill in the art that based on the design and thickness of the fifth dielectric layer 1668, the sixth dielectric layer 1674 may be optional. Specifically, the distance between the printed third conductive layer 1652 and a soon to be printed fourth conductive layer (not shown) is a predetermined distance based on the design of the ACMWT. As such, the height of the fifth dielectric layer 1668 is either equal to this predetermined distance if the sixth dielectric layer 1674 is not utilized or the height of the combination of the fifth dielectric layer 1668 and the sixth dielectric layer 1674 is equal to the predetermined distance.

In FIG. 16J, a cross-sectional view of a composite printed structure 1678 of the eighth combination 1672 with a printed fourth conductive layer 1680 is shown in accordance with the present disclosure. The printed fourth conductive layer 1680 is printed on a portion of the top surface 1676 of the printed sixth dielectric layer 1674 and has a fourth width 1682 (that is less than the first width 1606). The printed fourth conductive layer 1680 is the PAE 200 with the antenna slot 204 and the composite printed structure 1678 is the dielectric structure (e.g., dielectric structure 104).

In FIG. 16K, a cross-sectional view of a combined printed structure 1683 of the ACMWT is shown in accordance with the present disclosure. In this view, the waveguide walls 1684 (e.g., waveguide walls 116 or waveguide wall 304) are attached to the composite printed structure 1678 on the top surface 1676 of the printed sixth dielectric layer 1674.

In this example, as described in relation to FIG. 6, the ACMWT may include an optional cavity (that may be filled with air) about the printed second conductive layer 1624 (i.e., the inner conductor 106). This optional cavity may be formed within the printed third dielectric layer 1640. In this example, the printed third dielectric layer 1640 may include sub-sections of the printed third dielectric layer 1640 to produce at least one cavity that may be about (i.e., surround) the printed second conductive layer 1624.

As discussed earlier, the ACMWT may also include printing (or attaching by other means) a rigid surface layer (not shown) on the top surface 1676 of the printed sixth dielectric layer 1674 so as to establish a rigid base for the waveguide walls 1684. The thickness of this rigid surface layer may vary based on the design of the ACMWT such as a smaller thickness as shown in FIGS. 8A and 8B to a thickness that is approximately equal to the waveguide length 904 as shown in FIGS. 9A through 9C.

In FIG. 17, a flowchart is shown of an example implementation of method 1700 for fabricating the ACMWT (i.e., ACMWT 100, 300, 500, 600, 800, and 900) utilizing a 3-D additive printing process in accordance with the present

disclosure. The method 1700 is related to the method for fabricating the ACMWT utilizing the additive 3-D printing process as shown in FIGS. 16A-16K.

The method 1700 starts by printing 1702 the first conductive layer 1602. The first conductive layer 1602 includes a top surface 1604 and has a first width 1606 with a first center 1608. The first conductive layer 1602 is the bottom conductor 112 configured as a reference ground plane. The method 1700 then includes printing 1704 the first dielectric layer 1612 on the top surface 1604 of the first conductive layer 1602. The first dielectric layer 1612 includes a top surface 1614. The method 1700 then includes printing 1706 the second dielectric layer 1618 (with a top surface 1620) on the top surface 1614 of the first dielectric layer 1612. The method 1700 then includes printing 1708 the second conductive layer 1624 on the top surface 1620 of the second dielectric layer 1618. The second conductive layer 1624 has a top surface 1626 and a second width 1628, where the second width 1628 is less than the first width 1606. Moreover, the second conductive layer 1624 is the inner conductor (e.g., inner conductor 106). The method 1700 further includes printing 1710 the third dielectric layer 1640 (with a top surface 1642) on the top surface 1626 of the second conductive layer 1624 and on the top surface 1620 on of the second dielectric layer 1618. The third dielectric layer 1640 has a top surface 1642. The method 1700 then includes optionally printing 1712 the fourth dielectric layer 1646 (with a top surface 1648) on the top surface 1642 of the third dielectric layer 1640. As discussed earlier in relation to FIGS. 16A to 16K, it is appreciated by those of ordinary skill in the art that based on the design and thickness of the third dielectric layer 1640, the fourth dielectric layer 1646 is optional. The distance between the printed second conductive layer 1624 and the printed third conductive layer 1652 is a predetermined distance based on the design of the ACMWT. As such, the height of the third dielectric layer 1640 is either equal to this predetermined distance (if the fourth dielectric layer 1646 is not utilized) or the height of the combination of the third dielectric layer 1640 and the fourth dielectric layer 1646 is equal to the predetermined distance.

Moreover, the method 1700 includes printing 1714 the third conductive layer 1652 on the top surface 1648 of the fourth dielectric layer 1646 if the fourth dielectric layer 1646 is present or on the top surface 1642 of the third dielectric layer 1640 if the fourth dielectric layer 1646 is not present. For purposes of ease of illustration, for this example, it will be assumed that the fourth dielectric layer 1646 is present; however, it is appreciated that the following description may be modified accordingly if the fourth dielectric layer 1646 is not present.

The third conductive layer 1652 has a top surface 1654 and a third width 1656, where the third width 1656 is less than the first width 1606. The third conductive layer 1652 is a CE (e.g., CE 502). The method 1700 then includes printing 1716 a fifth dielectric layer 1668 on the top surface 1648 of the fourth dielectric layer 1646 and optionally printing on the top surface 1654 of the third conductive layer 1652. The fifth dielectric layer 1668 has a top surface 1670. The method then includes optionally printing 1718 a sixth dielectric layer 1674 on the top surface 1670 of the fifth dielectric layer 1668, where the sixth dielectric layer 1674 has a top surface 1676.

As discussed earlier in relation to FIGS. 16A to 16K, it is again appreciated by those of ordinary skill in the art that based on the design and thickness of the fifth dielectric layer 1668, the sixth dielectric layer 1674 is optional. Specifically,



in addition to the distance between the printed second conductive layer **1624** and the printed third conductive layer **1652** being a predetermined distance based on the design of the ACMWT, the distance between the printed third conductive layer **1652** and the printed fourth conductive layer **1680** is also a second predetermined distance based on the design of the ACMWT. As such, the height of the fifth dielectric layer **1668** is either equal to the second predetermined distance if the sixth dielectric layer **1674** is not utilized or the height of the combination of the fifth dielectric layer **1668** and the sixth dielectric layer **1674** is equal to the second predetermined distance. Again, for purposes of ease of illustration, for this example, it will be assumed that the sixth dielectric layer **1674** is present; however, it is appreciated that the following description may be modified accordingly if the sixth dielectric layer **1674** is not present.

The method then includes printing **1720** the fourth conductive layer **1680** on the top surface **1676** of the sixth dielectric layer **1674** to produce a PAE (e.g., PAE **200**) with an antenna slot (e.g. antenna slot **204**). The fourth conductive layer **1680** has a fourth width **1682**, where the fourth width **1682** is less than the first width **1606**. The fourth conductive layer **1680** includes an antenna slot within the fourth conductive layer **1980** that exposes the top surface **1676** of the sixth dielectric layer **1674** through the fourth conductive layer **1680**.

The method **1700** then further includes attaching **1722** the waveguide to the top surface **1676** of the sixth dielectric layer **1674**. The method **1700** then ends.

In this example, the method **1700** may utilize a sub-method where one or more of the first conductive layer **1602**, second conductive layer **1624**, third conductive layer **1652**, and fourth conductive layer **1680** are formed by a subtractive method (e.g., wet etching, milling, or laser ablation) of electroplated or rolled metals or by an additive method (e.g., printing or deposition) of printed inks or deposited thin-films.

It will be understood that various aspects or details of the invention may be changed without departing from the scope of the invention. It is not exhaustive and does not limit the claimed inventions to the precise form disclosed. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation. Modifications and variations are possible in light of the above description or may be acquired from practicing the invention. The claims and their equivalents define the scope of the invention.

In some alternative examples of implementations, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

The description of the different examples of implementations has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the examples in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different examples of implementations may provide different features as compared to other desirable examples. The example, or examples, selected are chosen and described in order to best explain the principles of the examples, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for

various examples with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. An aperture coupled microstrip-to-waveguide transition, comprising:
  - a plurality of dielectric layers forming a dielectric structure, wherein a top dielectric layer from the plurality of dielectric layers includes a top surface;
  - an inner conductor formed within the dielectric structure;
  - a patch antenna element formed on the top surface;
  - a coupling element formed within the dielectric structure;
  - a bottom conductor;
  - an antenna slot within the patch antenna element; and
  - a waveguide comprising at least one waveguide wall and a waveguide backend, wherein the waveguide backend has a waveguide backend surface that is a portion of the top surface of the top dielectric layer, wherein the waveguide backend surface and the at least one waveguide wall form a waveguide cavity within the waveguide, wherein the patch antenna element is located within the waveguide cavity at the waveguide backend surface, wherein the patch antenna element is a conductor, wherein the dielectric structure is configured to support a transverse electromagnetic signal during use, and wherein the waveguide is configured to support a transverse electric signal and a transverse magnetic signal during the use.
2. The aperture coupled microstrip-to-waveguide transition of claim **1**, wherein the antenna slot is angled along the patch antenna element with respect to the inner conductor.
3. The aperture coupled microstrip-to-waveguide transition of claim **1**, wherein each dielectric layer from the plurality of dielectric layers comprises a dielectric laminate material.
4. The aperture coupled microstrip-to-waveguide transition of claim **1**, wherein the dielectric structure comprises a stack-up height and a dielectric structure width, wherein the inner conductor is located in a middle dielectric layer within the dielectric structure, wherein the middle dielectric layer is approximately at a center position equal to approximately half of the stack-up height, and wherein the inner conductor comprises an inner conductor center located within the dielectric structure, the inner conductor center approximately at a second center position equal to approximately half of the dielectric structure width.
5. The aperture coupled microstrip-to-waveguide transition of claim **1**, wherein each dielectric layer from the plurality of dielectric layers comprises a dielectric laminate material, and wherein the inner conductor is a stripline or microstrip conductor.
6. The aperture coupled microstrip-to-waveguide transition of claim **1**, wherein the coupling element is formed within the dielectric structure above the inner conductor and below the patch antenna element.
7. The aperture coupled microstrip-to-waveguide transition of claim **6**, wherein the inner conductor comprises an inner conductor length and an inner conductor width that are predetermined to approximately optimize electromagnetic coupling between the transverse electromagnetic signal on the inner conductor and the transverse electric signal or the transverse magnetic signal in the waveguide at a predetermined operating frequency.
8. The aperture coupled microstrip-to-waveguide transition of claim **7**, wherein the coupling element is a stub, wherein the coupling element comprises a coupling element length, a coupling element width, and is at an angle with respect to the inner conductor, and wherein the coupling

element length, the coupling element width, and the angle are predetermined to approximately optimize electromagnetic coupling between the transverse electromagnetic signal on the inner conductor and the transverse electric signal or the transverse magnetic signal in the waveguide at a predetermined operating frequency.

9. The aperture coupled microstrip-to-waveguide transition of claim 8, wherein the patch antenna element is circular and the antenna slot is rectangular, wherein the patch antenna element comprises a radius, wherein the antenna slot has a slot length, a slot width, and is at an angle with respect to the inner conductor, and wherein the radius of the patch antenna element, the slot length, the slot width, and the angle are predetermined to optimize electromagnetic coupling between the transverse electromagnetic signal on the inner conductor and the transverse electric signal or the transverse magnetic signal in the waveguide at a predetermined operating frequency.

10. The aperture coupled microstrip-to-waveguide transition of claim 1, further including a cavity formed within the dielectric structure above the inner conductor and below the patch antenna element.

11. The aperture coupled microstrip-to-waveguide transition of claim 10, wherein the coupling element is formed within the dielectric structure above the cavity and below the patch antenna element.

12. The aperture coupled microstrip-to-waveguide transition of claim 10, wherein the cavity is filled with air, and wherein the inner conductor includes a portion located within the cavity.

13. A method for fabricating an aperture coupled microstrip-to-waveguide transition utilizing a lamination process, the method comprising:

patterning a first conductive layer on a bottom surface of a first dielectric layer to produce a bottom conductor, wherein the first dielectric layer includes a top surface;

patterning a second conductive layer on a top surface of a second dielectric layer to produce an inner conductor, wherein the second dielectric layer includes a bottom surface;

laminating the bottom surface of the second dielectric layer to the top surface of the first dielectric layer to produce a first combination;

patterning a third conductive layer on a top surface of a third dielectric layer to produce a patch antenna element with an antenna slot, wherein the third dielectric layer includes a bottom surface;

patterning a fourth conductive layer on a top surface of a fourth dielectric layer to produce a coupling element, wherein the fourth dielectric layer includes a bottom surface;

laminating the bottom surface of the fourth dielectric layer to the top surface of the second dielectric layer to produce a second combination;

laminating the bottom surface of the third dielectric layer to the top surface of the fourth dielectric layer to produce a composite laminated structure, wherein the composite laminated structure is a dielectric structure; and

attaching a waveguide wall to the composite laminated structure.

14. The method of claim 13, wherein the fourth dielectric layer includes sub-sections of the fourth dielectric layer to produce at least one cavity, and wherein laminating the bottom surface of the fourth dielectric layer to the top

surface of the second dielectric layer to produce the second combination includes forming the at least one cavity about the second conductive layer.

15. The method of claim 14, wherein the first conductive layer, the second conductive layer, the third conductive layer, and the fourth conductive layer are conductive metals.

16. The method of claim 15, wherein at least one of the first conductive layer, the second conductive layer, the third conductive layer, and the fourth conductive layer is formed by a subtractive method of electroplated or rolled metals or is formed by an additive method of printed inks or deposited thin-films, and wherein the subtractive method includes wet etching, milling, or laser ablation.

17. The method of claim 13, further comprising laminating a rigid surface layer on the composite laminated structure.

18. A method for fabricating an aperture coupled microstrip-to-waveguide transition utilizing a three-dimensional additive printing process, the method comprising:

printing a first conductive layer having a top surface and a first width, wherein the first width has a first center and wherein the first conductive layer is a bottom layer configured as a reference ground plane;

printing a first dielectric layer on the top surface of the first conductive layer, wherein the first dielectric layer has a top surface;

printing a second dielectric layer on the top surface of the first dielectric layer, wherein the second dielectric layer has a top surface;

printing a second conductive layer on the top surface of the second dielectric layer, wherein the second conductive layer has a top surface and a second width, wherein the second width is less than the first width, and wherein the second conductive layer is an inner conductor;

printing a third dielectric layer on the top surface of the second conductive layer and on the top surface on the second dielectric layer, wherein the third dielectric layer has a top surface;

printing a third conductive layer on the top surface of the third dielectric layer, wherein the third conductive layer has a top surface and a third width, wherein the third width is less than the first width, and wherein the third conductive layer is a coupling element;

printing a fourth dielectric layer on the top surface of the third conductive layer and on the top surface of the third dielectric layer, wherein the fourth dielectric layer has a top surface; and

printing a fourth conductive layer on the top surface of the fourth dielectric layer to produce a patch antenna element with an antenna slot, wherein the fourth conductive layer has a fourth width, wherein the fourth width is less than the first width, and wherein the fourth conductive layer includes the antenna slot within the fourth conductive layer that exposes the top surface of the fourth dielectric layer through the fourth conductive layer; and

attaching a waveguide wall to the fourth dielectric layer.

19. The method of claim 18, wherein the third dielectric layer includes sub-sections to produce at least one cavity.

20. The method of claim 18, further comprising: printing a fifth dielectric layer on the top surface of the third dielectric layer, wherein the fifth dielectric layer has a top surface, and

printing a sixth dielectric layer on the top surface of the fourth dielectric layer, wherein the sixth dielectric layer has a top surface, wherein printing the third conductive

layer on the top surface of the third dielectric layer includes printing the third conductive layer on the top surface of the fifth dielectric layer, and wherein printing the fourth conductive layer on the top surface of the fourth dielectric layer to produce the patch antenna 5 element includes printing the sixth dielectric layer on the top surface of the fourth dielectric layer and printing the fourth conductive layer on the top surface of the sixth dielectric layer.

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